Allocation of Cognitive Resources in Translation
an eye-tracking and key-logging study

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PhD thesis

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Copenhagen Business School

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Allocation of cognitive resources in translation: an eye-tracking and key-logging study

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Kristian Tangsgaard Hvelplund
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February 2011

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List of abbreviations

AU	Attention unit
LMER	Linear mixed-effects regression
LTM	Long-term memory
mm	millimetres
ms	milliseconds
PAU	Parallel attention unit
SL	Source language
SM	Sensory memory
ST	Source text
STAU	Source text attention unit
STM	Short-term memory
TAP	Think-aloud protocol
TL	Target language
TT	Target text
TTAU	Target text attention unit
WM	Working memory

Chapter 1

Introduction

The present study is an empirical investigation of translators' allocation of cognitive resources during the translation process, and it aims at investigating how translators' mental processing resources are put to use during translation. The study bases its analyses on quantitative eye-tracking and key-logging data collected from translation experiments.

Although the human cognitive system contributes strongly to making us unique as individuals, it is nevertheless obvious that we also share many cognitive features. This is also the case with translators. Though translators may all process their translations differently in some respects, there are also shared and to some extent predictable behaviours. It is the core object of the present study to identify these predictable behaviours and patterns of uniformity in translators' allocation of cognitive resources. Four factors thought to potentially co-determine translators' allocation of cognitive resources are considered: the type of processing (e.g. source text processing or target text processing), translational expertise, source text difficulty and time pressure. With respect to the *type of processing*, it is expected that cognitive resources are allocated differently during source text processing and during target text processing because they involve two different types of cognitive operations, i.e. language comprehension and language production. As regards *translational expertise*, it is anticipated that expert translators and non-expert translators allocate cognitive resources differently since the two groups differ with respect to translation skills. *Source text difficulty* is expected to have an effect on translators' allocation of cognitive resources since more cognitive resources are required in the translation of a difficult text than in the translation of an easy text. Finally, with respect to *time pressure* during translation, it is anticipated that the allocation of cognitive resources is different under time pressure than under no time pressure because less time is available to perform the same cognitive operations. This study will attempt to establish a quantitative basis for these intuitions in order to improve the understanding of translators' allocation of cognitive resources in translation.

The present study focuses on a group of indicators of cognitive resource allocation, which is based on the premise that the activity of translating involves the repeated shifting of the focus of attention between the source text and the target text. It is assumed that the shifting of attention is more or less voluntary, and it follows from this premise that the production of a translation is made up of units of attention or *attention units* that occur between each attention shift. During each attention unit, cognitive resources are allocated either to comprehending the source text or producing the target text. On this basis, three indicators are employed to evaluate translators' allocation of cognitive resources: (1) the *combined* duration of attention units, (2) the duration of *individual* attention units and (3) *pupil size* during individual attention units. Each indicator is taken to index one aspect of cognitive resource allocation: the combined duration of attention units reflects the translator's overall distribution of cognitive resources, the duration of individual attention units reflects the translator's management of cognitive resources and pupil size reflects the processing load, i.e. the cognitive load, which is placed on the translator's cognitive system.

1.1 Research questions

The underlying assumption of the present study is that the allocation of cognitive resources varies in different settings. Based on this assumption, three research questions are formulated, each of which deals with one aspect of the allocation of cognitive resources:

R1: *What is the distribution of cognitive resources during translation?*

R2: *How are cognitive resources managed during translation?*

R3: *How does cognitive load vary during translation?*

1.2 Theoretical basis

Drawing on research from several disciplines, the study falls mainly within the process-oriented translation paradigm and within the more general field of cognitive psychology (e.g. Neisser 1967, Anderson 2000, Eysenck and Keane 2010). The allocation of cognitive resources in translation is essentially an information processing task (e.g. Newell and Simon 1972), and the study therefore applies models and research from cognitive psychology in order to develop a theoretical framework on which the study's hypotheses are formulated and evaluated. From the field of cognitive psychology, theories of working memory (Baddeley and Hitch 1974, Baddeley 1986, 2000) and of a central executive system (Baddeley 2007) are used to examine the cognitive mechanisms that underlie human information processing. Research in language comprehension (Kintsch 1988, 1998, Padilla *et al*. 1999, Anderson 2000) and language production (Kellogg 1996, Olive 2004) from the fields of cognitive psychology, translation process research and text production research are employed to identify and qualify the cognitive subprocesses that are expected to be involved in source text processing and target text processing. The study also considers theoretical and empirical research concerning the coordination of language comprehension and language production. It has been suggested that comprehension and production occur sequentially (e.g. Seleskovitch 1976), in parallel (e.g. de Groot 1997) or both sequentially and in parallel (e.g. Ruiz *et al*. 2008). Finally, research using eye tracking and key logging as indicators of cognitive processing (e.g. Just and Carpenter 1980, Jakobsen 1998 and 1999, Rayner 1998, Duchowski 2007) is introduced to qualify the present study's analyses of eye-tracking and key-logging data. The study's analyses rest on the overall assumption that eye-tracking data can be interpreted as correlates of ongoing cognitive processing of the source text or the target text and that key-logging data can be interpreted as correlates of target text processing.

1.3 Methodology and data

Data from a series of translation experiments, carried out at the Copenhagen Business School, are used to investigate the study's three research questions. To help evaluate the effects of differences in translational expertise, data are collected from two groups of participants: 12 professional translators and 12 student translators. To help evaluate the effects of differences in source text difficulty, the 24 translators translate three texts that vary with respect to their levels of complexity. Finally, in order to help evaluate the effects of differences in time pressure, two of the three texts are translated under varying levels of time constraint while one is translated under no time constraint.

The study's analyses rely on translation process data which are collected with two non-intrusive data elicitation methods: key logging and eye tracking. Key-logging data are interpreted as evidence of ongoing target text processing and eye-tracking data are interpreted as evidence of ongoing source text processing or ongoing target text processing, depending on where the translator is looking. With respect to the eye-tracking data, it is generally assumed that eye movements can be interpreted as correlates of ongoing cognitive processing (Just and Carpenter 1980); that is, it is assumed that the eyes are fixated on a word as long as the word is being cognitively processed. For the present study, it is expected that the combination of key logging and eye tracking provides a more complete representation of the translation process than if only one method was used.

The eye-tracking and key-logging data are analysed statistically using inferential mixed-effects modelling. Mixed-effects modelling is considered useful to the study's analyses of data, which come from naturalistic experiments, as it takes into account random variation between the study's participants.

Tobii 1750 / ClearView

Key-logging and eye-tracking data are collected with the *Tobii 1750* eye tracker and the proprietary software *ClearView*. The Tobii 1750 eye tracker is a remote tracker that looks like a normal flat screen computer monitor. Aided by the ClearView software, the eye tracker collects eye movement data with a high degree of spatial and temporal accuracy; ClearView also registers typing events.

Translog

Translog is a computer program that registers and logs typing and mouse events in real time. It was developed as a tool to investigate cognitive processing during translation (Jakobsen 1998: 74). In this study, Translog is used to present the experimental source texts and to display the target text output. The Translog user interface is divided into two main areas: a source text window, which occupies the upper half of the screen, and a target text window, which occupies the lower half of the screen.

R

The programming language *R* is used to analyse the eye-tracking and key-logging data statistically using linear mixed-effects modelling. R offers a wide range of statistical analysis tools, including linear and non-linear modelling, and it provides graphical illustrations of the statistical analyses.

1.4 Delimitation

Other data elicitation methods, e.g. introspection and retrospection, could have been employed to provide further indication of the translator's allocation of cognitive resources during the translation process. For instance, think-aloud protocols (TAPs) (e.g. Krings 1986, Jääskeläinen and Tirkkonen-Condit 1991, Jääskeläinen 1999) could provide verbalised data about the object of the translator's attention in situations in which no eye-tracking data or key-logging data are registered. The use of TAPs, however, entails the risk that the *research process* may affect the *translation process* (Gile 1998: 75); more specifically, the allocation of the translator's limited cognitive resources to both verbalising and translating may affect negatively the reliability of the translation process data as the data would not reflect translating exclusively. Retrospective interview data and questionnaire data may also provide some indication of the translation process; these types of data are not collected, however, since they do not reflect the translator's allocation of cognitive resources *during* the translation process. As noted earlier, the methods of eye tracking and key logging are considered the most reliable data elicitation methods, in terms of completeness, for the present study of the allocation of cognitive resources.

This study of cognitive resource allocation during translation focuses on the translation *process*, and analysis of the translation *product* is not carried out. It might be, however, that analysis of the translation product, e.g. translation quality assessment, could provide further explanation of the study's findings, but the data from such an analysis would essentially not be within the scope of this thesis which is interested in the allocation of cognitive resources *during* translation.

1.5 Structure of the thesis

The thesis is organised in such a way that Chapters 2 and 3 provide the theoretical framework which is used in the study's empirical investigation. Chapters 4 and 5 account for the study's methodological framework and Chapter 6 reports on the empirical findings.

Chapter 2 outlines theoretical reflections on the translation process as a cognitive phenomenon and it reviews empirical studies that have investigated the relationship between cognitive resources and the processes in translation, translational expertise, source text difficulty and time pressure.

Chapter 3 introduces concepts concerning the human memory system, language comprehension and language production in order to identify and qualify the cognitive operations and processes involved in translation. It then considers concepts which are of relevance in the measurement of the translation process. Hypotheses are presented at the end of the chapter.

Chapter 4 provides an account of the study's research design by presenting the participants, the experimental texts, the experimental time constraints and the presentation sequence in which the experimental texts are presented.

Chapter 5 describes the procedure by which translation process data are collected and how the data are prepared and coded. The chapter also introduces the statistical methods used to analyse the data.

Chapter 6 presents the results of the study's three analyses of translators' allocation of cognitive resources in translation. The results are discussed in relation to the hypotheses presented in Chapter 3.

Chapter 7 sums up the study's main findings and its strengths and weaknesses. Future avenues of research are discussed.

Chapter 2

Translation and cognitive resources

2.1 Translation and the cognitive processes

> (T)ranslating processes, i.e. those series of operations whereby actual translations are derived from actual source texts (...), are only *indirectly* available for study, as they are a kind of 'black box' whose internal structure can only be guessed, or tentatively reconstructed.
>
> Toury (1985: 18)

Empirical research into the cognitive workings of translation dates back to the early 1980's. Translation researchers have attempted to discover the content of the 'black box' described by Toury using varies methods such as think-aloud protocols (TAPs), retrospective analysis, key logging and eye tracking. This research has to some extent rested on theory and concepts from the cognitive sciences, in particular cognitive psychology, psycholinguistics and experimental psychology (Shreve and Koby 1997: xii). For instance, the concept of a *working memory* from cognitive psychology (Baddeley and Hitch 1974, Baddeley 1986, 2000), which is a theorised memory construct that stores and processes information temporarily, has been used in translation process research to explain the manipulation of information from source text (ST) to target text (TT) (e.g. Bell 1998, Halskov Jensen 1999 and Dragsted 2004). Also, the notion of a *long-term working memory* (cf. Ericsson and Kintsch 1995) has been introduced to illustrate the cognitive advantage that skilled translators hold over novice ones (Dragsted 2004). Research in monolingual language comprehension and research in monolingual text production have also been introduced to peer into the 'black box' of translation processes. With respect to text production in translation, Hayes and Flower's (1986) model of monolingual writing has been applied to model the text production process(es) involved in translation (Englund Dimitrova 2005), and with respect to monolingual language comprehension, Kintsch's (1988) construction-integration model has been applied as a framework for modelling comprehension in translation (Padilla *et al*. 1999). The use of theories and concepts from cognitive psychology in the investigation of the translation process provides a strong basis for interpreting the cognitive operations of translation. The present study will also rely on such theories and concepts in order to gain greater insight into the allocation of cognitive resources in translation.

The first half of this chapter outlines some theoretical reflections on the definition and characterisation of the cognitive processes involved in translation; the second half of the chapter is devoted to a review of empirical studies that have provided some quantitative accounts of the cognitive processes involved in translation. Particular focus is given to studies that can provide indication of translators' allocation of cognitive resources during the translation process.

The translation process

Translation is often considered a process which involves the interaction and coordination of several mental processes. Shreve and Koby (1997: xi) point out that the translation process involves four main processes: *comprehension* and *interpretation* of the source language (SL) message, *transposition* of the SL message into the target language (TL) and *expression* of the transposed message in the TL. During this process, long-term memory stores are activated from which linguistic and cultural knowledge is drawn upon to create a translation of the ST. Simultaneously, Shreve and Koby note, working memory temporarily stores current information of the translator's present focus of attention as well as of other translation units, which are relevant to the one currently being processed. A somewhat broader perspective on the translation process is described by Hansen (2003):

> The translation process is defined as everything that happens from the moment the translator starts working on the source text until he finishes the target text. It is all encompassing, from every pencil movement and keystroke, to dictionary use, the use of the internet and the entire thought process that is involved in solving a problem or making a correction - in short everything a translator must do to transform the source text to the target text.
>
> Hansen (2003: 26)

In this definition, translation is a much more all-encompassing task, which involves an array of sub-tasks in addition to the cognitive processes involved in meaning extraction from the ST and meaning recreation in the TL. This means that also tasks which are not defined in a cognitive context fall within the scope of the translation process.

The above views represent two different interpretations of the notion of the 'translation process': in the broader sense, the translation process is composed of those *tasks* which eventually lead to a TL representation of a SL message. In the more narrow cognitive view, the translation process is defined as a set of *mental operations*, or cognitive processes, that are involved in transforming a message from one language to another. This study, which concerns the allocation of cognitive resources during translation, considers the translation process a cognitive phenomenon. Below, two models (Gile 1995 and Danks and Griffin 1997) are considered in order to outline the cognitive processes involved in translation and their interaction.

Gile’s sequential model of translation

Gile’s (1995: 101-106) sequential model of translation is an illustration of the flow of information during the translation process. The model focuses on two overall phases that make up the translation process; one phase involves ST comprehension and the other phase involves TT reformulation. Both comprehension and reformulation rely on linguistic knowledge and extralinguistic knowledge in order to comprehend the ST and reformulate the ST meaning in the TL, cf. Figure 2a below:

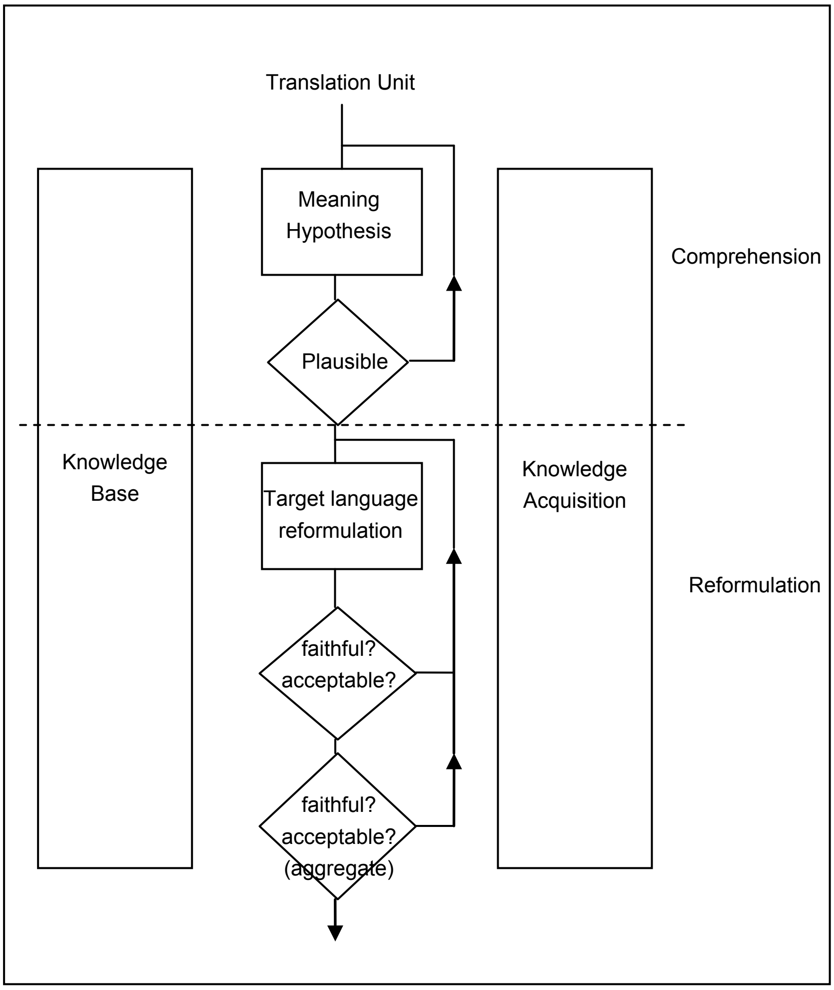

Figure 2a: Gile’s sequential model of translation (from Gile 1995: 102).

In a comprehension phase, the translator constructs a meaning hypothesis of an ST unit. The meaning hypothesis is tested for plausibility, and in the event it is rejected, a new meaning hypothesis is constructed. This process of meaning hypothesis construction is repeated until a plausible meaning of the ST unit is established. When a meaning hypothesis has been accepted, the translator moves on to TT reformulation. During TT reformulation, the translator recreates an equivalent of the ST unit in the TL. The translator tests the TT unit for acceptability until a satisfactory rendering of the original ST unit has been achieved (ibid. 102-105). Gile points out that the two phases are *not* specific to the translation process; these processes also describe language comprehension and language production in 'ordinary' monolingual comprehension and production tasks (ibid. 106). As in monolingual language comprehension and language production, the translator draws on her existing knowledge base (i.e. SL Knowledge, TL Knowledge and World Knowledge) in order to establish the meaning of an ST unit or in order to create a TL message. She may also need to acquire new knowledge (knowledge acquisition) by consulting external resources (e.g. dictionaries, parallel corpora etc.) if her knowledge base does not contain the information needed to comprehend the ST or reformulate the ST message in the TL.

Gile's model implicitly assumes that the allocation of cognitive resources in translation alternates between ST comprehension and TT reformulation in a sequential manner. This is not necessarily the case, as it has been found that ST comprehension and TT reformulation in fact occur simultaneously (e.g. Ruiz *et al.* 2008: 491). Such parallel ST/TT processing does not fit easily into Gile's model. The model nevertheless provides a practical account of the two basic processes of ST meaning extraction and recreation of the ST message in the TL. It does not, however, specifically suggest an itemisation from a cognitive perspective of the subprocesses that are involved in the translation process, for instance reading, typing, syntactic, semantic, pragmatic analysis, etc.

Danks and Griffin's model of the translation process

A model which proposes a more detailed account of the translation process than Gile's is that of Danks and Griffin (1997). Unlike Gile, Danks and Griffin (ibid. 166) stress that comprehension in translation is different from 'normal' comprehension. It is a goal-oriented intention-driven process which is guided by: "[the] concerns about writer's intent, the translator's intent, and end user's intent [which] dictate the level of comprehension." They continue stressing that "we would contend that [translation and interpretation] are not – emphasize *not* – just reading and listening, speaking and writing, with conversion from source to target language inserted in between (...) although many of the subprocesses are the same, the structure of the whole processes changes" (ibid. 163). Aware of the limitations of conventional models of monolingual comprehension and production processes, Danks and Griffin developed a model which describes the cognitive processes involved in translation:

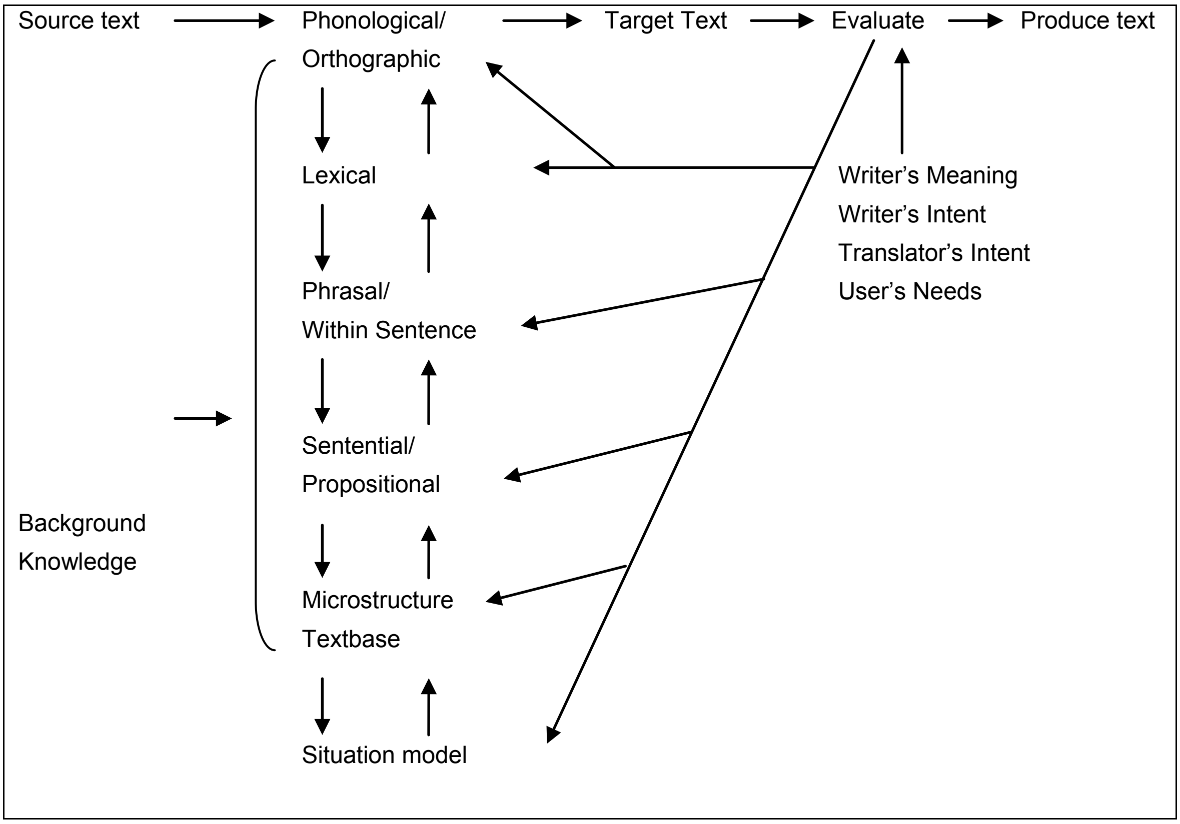

Figure 2b: A model of the translation process (from Danks and Griffin 1997: 174).

In written translation, processing of the ST message firstly involves orthographic analysis of ST words. Using her background knowledge, the translator engages in lexical analysis in order to identify the meaning of an ST word, and the identified word is then placed in a phrasal context. Sentential and propositional analysis is then carried out and mental representations of the source text message are formed. This process of comprehension occurs in a bottom-up as well as in a top-down manner: "the translator is moving up and down while he or she is translating" (ibid. 174).

It is not apparent from the model if TT processing begins only when a source text representation has become available *or* if TT production in fact begins during ST comprehension, but Danks and Griffin do point out that "the translator does not first comprehend the source text fully and only then begin the process of translation. Rather, we think that the translator is working on various possibilities for translation at the same time that he or she is comprehending the source text" (ibid.).

Danks and Griffin's model is a theoretical account of the translation process which rests mostly on intuitions and on models from neighbouring cognitive research disciplines. Aware that their model is an 'armchair' model, Danks and Griffin ask: "how do the task, text, and translator factors affect translation and interpretation performance? This chapter has attempted such an analysis from the armchair. The next step is to attempt it in the lab" (ibid. 175). The present study is such a lab attempt, which aims at examining empirically how various factors affect the allocation of cognitive resources in translation.

2.2 Empirical studies and allocation of cognitive resources

Various methods of tapping into the cognitive processes by which a translation comes into existence have been employed. Verbal reporting (Ericsson and Simon 1984) has been used to study the cognitive processes during translation. In translation experiments using concurrent TAPs (e.g. Krings 1986, Jääskeläinen and Tirkkonen-Condit 1991, Jääskeläinen 1999), the translator verbalises her thoughts as the translation is produced. There are some disadvantages, however, to the method of TAP. Jakobsen (2003: 78-79) found that the time it took to produce a translation increased significantly when translators had to think aloud while translating. Jakobsen (ibid. 77) suggested that translation speed was affected because translators were conscious of the translation setup itself and self-conscious of their own performance (in particular the professional translators, who were far less generous with their verbalisation than the student translators). In addition, both factors were considered negative contributors to the ecological validity of the experiment (ibid.). Another factor that may affect translation speed relates to constraints on the translator's cognitive capacity to perform simultaneously the tasks of verbalising and producing a translation (e.g. Gile 1998). Gile (ibid. 75) points out that "the numerous TAP (think-aloud-protocol studies) performed on translators over the past few years also entail a strong possibility of interaction between the research process and the translation process under study". It follows from Gile's note of caution that the simultaneous allocation of resources to the process of translating and to the process of verbalising may affect the reliability of TAP data negatively. It is very likely that concurrent attention to the two tasks compete for the translator's (limited amount of) cognitive processing resources. During such cognitive overload, there is the risk that the translation process is affected when the translator is verbalising.

Key-logging data have been used in translation process research since the late 1990's to investigate cognitive processing during translation (e.g. Jakobsen 1998, 1999, 2003, 2005, Hansen 1999, Jensen 2000, Alves 2003, Dragsted 2004, Immonen 2006, O'Brien 2006b, Pöchhacker *et al.* 2007, Mees *et al.* 2009). Key logging of writing processes in translation was suggested as a new method of tapping into cognitive processing during translation, which could complement qualitative methods such as the potentially intrusive method of think-aloud:

> the idea [is] that the process of writing a translation constitutes behaviour that can be studied quantitatively – across time – and interpreted as a correlate of mental processing. The assumption is further that it will be possible to triangulate qualitative and quantitative data and test hypotheses derived from analyses of qualitative data against quantitative data, and vice versa.
>
> Jakobsen (1998: 74).

Key logging has the main advantage that is does not interfere with the translation process itself. All typing events are registered without interfering with the translation process, and it thus constitutes a non-intrusive alternative to introspection. A shortcoming of the key logging methodology is, however, that the researcher is uninformed of the translator's object of attention during writing pauses.

Eye tracking has been used in studies investigating cognitive processing (see e.g. Rayner 1998 for an extensive overview) in psychology, the cognitive sciences and marketing research for several decades. In 2006, the Eye-to-IT project[1] sought to combine key logging with eye tracking. This combination makes it possible to identify which elements of the translation attracted the translator's visual attention during writing pauses (Mees 2009: 28). Eye tracking has since been used more and more in translation process research, and several studies have been carried out using eye tracking independently (e.g. O'Brien 2006a, Jakobsen and Jensen 2008, Pavlović and Jensen 2009, Jensen *et al.* 2009) or in combination with key logging (e.g. Dragsted and Hansen 2008, Sharmin *et al.* 2008). Recently, fMRI[2] has been suggested as a method of tapping into the translation process (Chang 2009).

In the following, relevant translation process studies are reviewed. The aim of the review is to explore findings from empirical research of the translation process and relate those findings to the present study's object of interest: the allocation of cognitive resources in translation. Also an aim of the review is to discuss and consider the appropriateness of research methods (TAP, key logging and eye tracking) in relation to investigating translators' allocation of cognitive resources. The studies that are discussed below constitute a sample of empirical translation process research.

Studies that are included in the review are selected on the basis of a set of criteria: (1) the study must provide enough quantifiable data so that observations or inferences

---

[1] The Eye-to-IT project was an EU-funded collaborative research project which ended in April 2009. Its aim was twofold: to study translation as a cognitive process and to develop a human-computer interface which would support the translator's translation process by prompting relevant feedback (http://cogs.nbu.bg/eye-to-it/).

[2] fMRI (functional Magnetic Resonance Imaging) is a neuroimaging technique that measures changes in blood flow in the brain (Eysenck and Keane 2010: 634). It provides spatial and temporal information about brain processes.

can be made with respect to the allocation of cognitive resources; this is important since it will create a basis on which hypotheses can be formulated and to which the findings of the present study can be related. (2) The study must report data from written translation experiments rather than from spoken translation experiments (i.e. interpreting experiments); from a cognitive perspective, written translation and spoken translation are quite different, and it would be problematic to compare findings across the two modes of translating. (3) The study's data must not rely on data from other studies that are reported here. In the event two or more studies report on the same data, they are discussed collectively. And (4) the study must clearly state the methods of data collection and analysis that were used; this is necessary in the discussion of the appropriateness of research methodology in relation to the present study.

The review is organised into four sections that each deals with one factor which is thought to affect translators' allocation of cognitive resources: type of processing, translational expertise, source text difficulty and time pressure. These four factors may be categorised according to factor *type*: implied factors, intrinsic factors and extrinsic factors. Implied factors are those factors which are innate to the object of interest; such a factor is processing type (section 2.2.1) in the sense that the translation process consists of subtypes of cognitive processes (e.g. ST comprehension and TT reformulation). Intrinsic factors are factors which principally depend on the translator's cognitive processing system, and they are therefore participant-dependent; such a factor is translational expertise (section 2.2.2). Lastly, extrinsic factors are factors that are mainly associated with the translation task or the translation situation; such factors are source text difficulty (section 2.2.3) and time pressure (section 2.2.4).

Table 2a lists the empirical studies that will be dealt with in the following sections. Some studies provide data about more than one factor; these studies will be considered several times, each time with particular focus on one factor. Although some studies use other methods than the one(s) indicated in the table's right-most column, only the method(s) of data elicitation that will be discussed in the review are listed.

Table 2a: A selection of empirical translation process studies

Author(s)	*Year*	*Processing type*	*Translational expertise*	*Source text complexity*	*Time pressure*	*Elicitation method(s)*
Jääskeläinen	1999	x	x			TAP
Halskov Jensen	1999			x		Key
Jensen[3]	2000				x	Key
De Rooze	2003				x	Key
Dragsted	2004		x	x		Key
Jakobsen & Jensen	2008	x	x			Eye
Dragsted & Hansen	2008			x		Eye + Key
Sharmin *et al.*	2008	x		x	x	Eye
Pavlović & Jensen	2009	x	x			Eye

2.2.1 Cognitive resources and the processes of translation

Translation process studies that have made a point of quantitatively identifying differences between ST processing and TT processing in translation are few and far between. Some studies nevertheless provide indication of differences in resource allocation between ST processing and TT processing. The discussion below has the specific goal of extracting information which may indicate how translators allocate cognitive resources to ST processing and TT processing. The studies are Jääskeläinen (1999), which relies on TAP data, and Jakobsen and Jensen (2008), Sharmin *et al*. (2008) and Pavlović and Jensen (2009), which rely on eye-tracking data.

Jääskeläinen (1999)

In her (1999) study, Jääskeläinen investigated the number of instances of verbalised ST processing and TT processing of four professional translators and four non-professional translators based on TAP data. Jääskeläinen distinguishes between four sub-categories of translation processing which are identified on the basis of the nature of the verbalised

[3] Although Jensen makes observations on differences between translators who do not share the same level of expertise, data from three groups, which each consists of only two participants, is here considered too small an amount of data to make generalisations about the allocation of cognitive resources.

material; these four categories are: ‘translation principles’, ‘source text processing’, ‘target text processing’ and ‘unspecified’. The category of ‘translation principles’ generally includes procedural comments and statements that indicate global translation strategies (1999: 178). The ‘source text processing’ category comprises verbalisations which reflect that the participant is engaging in ST comprehension (1999: 183). The third category of ‘target text processing’ involves verbalisations that are interpreted as the translator’s engagement in TT processing (1999: 190). Finally, the ‘unspecified’ category reflects that no attention is focussed on any of the three previous categories (1999: 199-200). The results from her study showed that translators verbalised TT processing far more than they verbalised ST comprehension: the aggregate number of ST processing instances was 172 (30 percent of all ST processing and TT processing instances) and TT processing instances was 392 (70 percent of all ST processing and TT processing instances) (1999: 201). Jääskeläinen does not provide explanation for the notable differences between ST processing and TT processing, however, based on the distribution of processing instances, it seems that TT processing occupies a larger share of the translator’s processing effort.

In terms of completeness, the TAP data are unable to convincingly demonstrate the object of the translator’s attention during the entirety of the translation process since they reflect only a limited portion of the processing that occurs during the translation process. The distribution of instances of ST processing and TT processing may therefore be misrepresentative of the actual distribution of cognitive resources devoted to ST processing and to TT processing, as instances of ST processing and TT processing are not necessarily verbalised to the same extent. Irrespective of the incompleteness of TAP, Jääskeläinen’s findings do, however, provide some tentative indication of the allocation of translators’ cognitive resources between the ST and the TT, with respect to their distribution as translators seem to be occupied more with TT processing than with ST processing.

Jakobsen and Jensen (2008)

Using eye tracking, Jakobsen and Jensen (2008) examined differences in reading while typing a translation. Six professional translators and six student translators translated a text of around 200 words from L2 English into L1 Danish. Translog was used to display the source text and the emerging target text. Eye movements were recorded using a Tobii 1750 eye tracker. Four dependent variables of eye movement were used as indicators of differences between ST processing and TT processing: total number of fixations, gaze time (total duration of fixations), mean fixation duration, and shifts in attention between the ST and the TT.[4]

The first indicator showed that the TT received more fixations overall than the ST, i.e. 882 fixations and 706 fixations, respectively. The second indicator showed that translators spent more time looking at the TT than at the ST (the means were 256 seconds and 200 seconds, respectively), corresponding well with Jääskeläinen's findings above which suggested that more processing effort is devoted to TT production than to ST comprehension. The third indicator revealed that mean fixation duration during TT processing was 259 ms and somewhat shorter during ST processing at 218 ms, which suggested that TT processing is more resource demanding than ST processing. Finally, the fourth indicator showed that the number of shifts between the ST area of the screen and the TT area of the screen amounted to 225, which corresponded to a mean shift frequency of 3.8 seconds. Jakobsen and Jensen (ibid. 120) suggest that translators' frequent shifts in visual attention between the ST and the TT entail frequent visual reorientation, which may disorient the translator and affect the speed of translation negatively.

These figures indicate that translators allocate more cognitive resources to TT processing than to ST processing as indicated, for instance, by processing *time* and processing *load* (fixation duration). In comparison to TAP, eye tracking seems to be at an advantage since eye-tracking data represent a more complete record of the translation process. In spite of this advantage, none of the differences in Jakobsen and Jensen's study turned out to be significant when paired samples t-tests on means were used. It is likely that there was simply too little data on which to base the analysis; a total of 12 participants is a fairly low number, in particular since the statistical analysis used a very small population of *means* to estimate the level of significance. It is possible that statistical significance would have been reached if the statistical analysis had been based on more data points. Although the figures only descriptively indicate that there are differences between ST processing and TT processing, there is some preliminary support for anticipating that TT processing requires more cognitive resources than ST processing. This intuition is supported by Sharmin *et al.*'s (2008) study, which was in fact able to identify a statistically significant relationship between processing type and differences in eye movement behaviour.

[4] Jakobsen and Jensen removed outlier values, e.g. fixation durations that were exceptionally long or exceptionally short (Jakobsen and Jensen 2008:108-115).

Sharmin *et al.* (2008)

In Sharmin *et al.*'s (2008) study, 18 student translators had their eye movements recorded while they translated three texts from L2 English into L1 Finnish. One aim of their study was to make observations on differences in fixation durations during ST reading and during TT reading. Using fixation duration as the dependent variable, Sharmin *et al.* found that TT fixations across the three experimental texts were significantly longer than ST fixations (the means were 266 ms and 212 ms, respectively). These findings are in line with those of Jakobsen and Jensen (2008), reported above, and they support a hypothesis which predicts that more cognitive resources are allocated to TT processing than to ST processing. Unlike Jakobsen and Jensen's findings, Sharmin *et al.*'s findings were significant. One possible explanation for the significant findings is that this study based its analyses on a slightly larger number of participants. If this is indeed the case, it would be favourable to base the analyses of a given study on process data from a fairly large number of translators.

Pavlović and Jensen (2009)

Pavlović and Jensen's (2009) study aimed at investigating directionality in translation using eye-tracking. 16 translators (eight professional translators and eight final year students of translation) translated one text from L1 Danish to L2 English and another from L2 English to L1 Danish. Due to problems with eye-tracking data quality, data from only four professional translators and four student translators were included in their analyses. The data quality criterion used to discriminate good quality from bad quality was one of mean fixation duration. Based on Rayner's (1998: 373) observation that mean fixation duration during reading is 225 ms, eye-tracking data from participants were excluded in which mean fixation duration was abnormally short (i.e. lower than 200 ms).

With respect to the comparison between ST processing and TT processing, Pavlović and Jensen hypothesised that (1) TT processing requires more cognitive effort than ST processing. They also hypothesised that (2) ST processing is cognitively more demanding when the ST is an L2 text (i.e. translating into the translator's mother tongue) than when the ST is an L1 text (i.e. translating out of the translator's mother tongue). For TT processing, they hypothesised (3) a reversed effect so that TT processing is cognitively more demanding when the TT is an L2 text than when the TT is an L1 text

Pavlović and Jensen employed three eye-movement indicators of cognitive effort: (a) total gaze time, which was the combined duration of fixations allocated to either ST processing or to TT processing, (b) fixation duration during ST processing and TT processing and (c) pupil dilation. Using paired t-tests, Pavlović and Jensen found significant effects in support of hypothesis 1 by all three eye-movement indicators. With respect to hypotheses 2 and 3, there were very few significant effects; in fact, only pupil dilation turned out to be significant for hypothesis 3. Nevertheless, the results with respect to hypothesis 1 strongly indicate that ST comprehension and TT production are two processes which differ in terms of the cognitive load placed on the translator's cognitive system. Like Jakobsen and Jensen's (2008) study, reported above, that of Pavlović and Jensen seems to suffer from the fact that the statistical analyses are based on very small populations of means. They point this out themselves: "with such a small sample, any free variable can cause havoc in the data" (2008: 108). It is possible that they would have been able to more confidently offer explanation for hypothesis confirmation or lack thereof if their population of data points had been larger.

In addition to the findings with respect to hypothesis 1, Pavlović and Jensen's study is also interesting as cognitive effort is measured using *several* indictors, instead of relying on just one indicator. It remains unclear, however, how these indicators differ from each other (or correlate) since the findings by one indicator conflicted with those by another (hypothesis 3). Gaze time and fixation duration, which are in large part under direct control of the translator, as she herself controls where to look, and pupil dilation (and constriction), which cannot be controlled intentionally, perhaps do not measure the same cognitive effect as the findings did not correlate.

2.2.2 Cognitive resources and translational expertise

Several process studies have compared translation process data from more skilled translators and from less skilled translators to examine how differences in translational expertise affect the translation process. The focus here is not to discuss what is expertise (cf. e.g. Ericsson *et al*. 2006) in relation to translation (cf. e.g. Englund Dimitrova 2005); rather, in the study of the allocation of cognitive resources in translation, the overall aim is to make observations on differences between two groups that are assumed not to share the same level of expertise. In the following, five process studies are reviewed that compare groups of translators that do not share the same level of expertise: Jääskeläinen (1999), who compared professional translators and non-professional translators, Dragsted (2004), Jakobsen and Jensen (2008) and Pavlović and Jensen (2009), who compared professional translators and student translators.

Jääskeläinen (1999)

Jääskeläinen's (1999) study, which was discussed also in section 2.2.1, found differences in the number of instances of processing, as indicated by verbalisations, between professional translators and non-professional translators.[5] Overall, the results showed that the total number of instances of processing was higher for professional translators than for non-professional translators (405 and 289, respectively) (ibid. 201). This was taken as evidence that professional translators engage in more problem-solving activities than non-professional translators. By cross-tabulating Jääskeläinen's findings across processing type (only ST processing and TT processing) and level of translational competence, the following figures are found:

Table 2b:[6] Total number of instances of ST processing and TT processing. The figures in parentheses indicate how many percent of the total (ST+ TT) belonged to each category.

	ST processing (percent)	*TT processing (percent)*
Professional translators	93 (27.8)	242 (72.2)
Non-professional translators	79 (34.5)	150 (65.5)

The professional translators' TAPs contained a total of 335 instances of ST processing and TT processing and the non-professional translator's protocols contained 229 instances of verbalisations. Jääskeläinen speculates that the higher percentage of instances of ST processing on the part of the non-professional translators reflects their lower proficiency in English. The lower number of ST processing instances than TT processing instances for both groups is explained by the level of ST difficulty, which was considered to be relatively easy (ibid. 202-203).

With respect to the allocation of cognitive resources, the higher number of ST and TT processing instances on the part of the professional translators could indicate that professional translators overall allocate more resources to translating than do the non-professional translators. The above figures of instances of ST processing and TT processing therefore do not support the general idea that non-professional translators struggle more with translation than professional translators. Indeed, it would seem that professional translators are the ones who struggle the most. It is, however, more likely that professional translators are better, or more generous, at verbalising their problem-

[5] The professional translators in Jääskeläinen's study were qualified translators who worked as translators at the time of the experiment. The non-professional translators (which she also refers to as 'educated laymen') had a relatively high level of education, they were in the same age group as the professional translators and they had sufficient knowledge of English (Jääskeläinen 1999: 91).

[6] The figures in Table 2b do not consider instances of translation principles and unspecified instances, as they cannot be categorised as ST processing or TT processing.

solving activities (cf. e.g. Jakobsen 2003: 77). This explanation is also suggested by Jääskeläinen herself (1999: 202), who refers to the less frequent verbalising in non-professional translators' TAPs as 'shallow processing'. With respect to the applicability of TAP to make quantifiable observations on differences between professional translators' and non-professional translators' allocation of cognitive resources, this method is perhaps not the best choice, since it essentially relies on the participant's ability to verbalise her thoughts throughout the translation process.

Dragsted (2004)

In the experiments for her PhD thesis, Dragsted (2004) had two groups of translators translate short texts from Danish L1 into English L2. One group (professional translators) consisted of six state-authorised translators with at least two years of experience and one group (student translators) consisted of six final-year students of translation. Key logging, in combination with questionnaires, was used to elicit translation process data. Dragsted (2004: 103) hypothesised that (1) the number of words in a translation unit (TU) will be higher among professional translators than among student translators, (2) professional translators and student translators behave differently with respect to the extent to which ST comprehension and TL production occur in parallel or separately, and (3) professional translators, unlike student translators, will have developed an extra memory component (long-term working memory, cf. Ericsson and Kintsch (1995)), which enables them to process larger TUs more quickly.

With respect to the first hypothesis, Dragsted observed that professional translators' TUs were generally longer and produced more quickly than those of the student translators, although no significant difference was able to support this. As regards the second hypothesis, Dragsted found that the professional translators' process data were characterised by more parallel processing of ST comprehension and TL production than were the student translators' data. One measure Dragsted used to test this hypothesis was by analysing the extent to which translators engaged in literal translation. Dragsted found that "professional translators (...) made less verbatim translation than students" (2004: 208). Dragsted's third hypothesis to do with an extra memory component on the part of the professional translators was found to be confirmed as the key-logging data showed that "professional translators have an ability, not normally present in students, to process large structures of information (TUs of more than 10 words), and (...) to retrieve such large amounts of information without this influencing the pausing time" (Dragsted 2004: 215).

Dragsted's study provides some very interesting observations on how professional translators and student translators allocate cognitive resources in translation; it is particularly interesting to the present study that it appears that professional translators are able to process more information in shorter time and that they engage in parallel ST processing and TT processing more so than less skilled translators. These observations strongly suggest that the allocation of cognitive resources during translation is different for professional translators and student translators. With respect to completeness and allocation of cognitive resources, analysis of key-logging data permits the researcher to make observations on the production aspect of translation. Phenomena relating to the comprehension aspect of translation are not as easily inferable and key logging alone is therefore not considered an ideal method of data elicitation, at least if used independently, in the investigation of cognitive resource allocation.

Jakobsen and Jensen (2008)

The study by Jakobsen and Jensen (2008), which was discussed also in section 2.2.1 above, compared eye movements of professional translators with those of student translators. The five dependent variables that were used to identify differences between professional translators and student translators were: total task time, total number of fixations, gaze time (total duration of fixations), mean fixation duration and shifts in attention between the ST and the TT. Overall, Jakobsen and Jensen found that student translators spent roughly 23 percent more time translating than did professional translators (945 seconds and 771 seconds, respectively); with respect to fixation count, professional translators' and student translators' mean fixation counts were very similar (1585 and 1598, respectively), but the distribution of fixations is notable as professional translators had far more TT fixations (958) than ST fixations (627) whereas student translators had fewer TT fixations (729) than ST fixations (869). The gaze time indicator revealed that the professional translators' total fixation duration was 433 seconds, while the student translators' was 478 seconds. The distribution here is also notable as professional translators looked for much longer at the ST (145 seconds) than at the TT (288 seconds). The reverse picture was found for the student translators (ST = 255 seconds and TT = 223 seconds). With respect to fixation duration, no appreciable difference was found between professional translators and student translators. Finally, professional translators' mean number of attention shifts between the ST and the TT was 190, whilst the figure for student translators was 259. In spite of notable differences between some of the means, none turned out to be significant. Assuming that the reason for the lack of significant findings has to do with the statistical method that was used, Jakobsen and Jensen's descriptive findings are nevertheless interesting as they provide tentative indication that professional translators and student translators allocate cognitive resources differently. Overall, student translators allocate more cognitive resources to the task of translation than do professional translators. Looking at differences between ST processing and TT processing, the two groups also process translation very differently: professional translators allocate considerably more cognitive resources to TT processing than do student translators; student translators instead seem to be engaged in ST processing much more than professional translators. Jakobsen and Jensen (2008: 119) speculate that these findings could indicate comprehension problems on the part of the student translators.

Pavlović and Jensen (2009)

The directionality study by Pavlović and Jensen (2009), which was considered above in relation to differences between ST processing and TT processing, hypothesised that student translators allocate more cognitive effort in translation than do professional translators. The findings were mixed as only one indicator (total gaze time) revealed significant differences between the two groups ($p = 0.009$). This indicator showed that student translators spent around 23 percent more time translating the two texts than did the professional translators. Average fixation duration was non-significant ($p = 0.9$) as was pupil dilation ($p = 0.07$). Although the findings offer only partial confirmation to the hypothesis, it is interesting to note that measures of total gaze time may be helpful in explaining differences between professional translators' and student translators' allocation of cognitive resources. Equally interesting is it to note that the differences in total gaze time were the only differences that were significant; as noted above, it could be that the three eye-movement indicators index different aspects of cognitive processing. It may also be that the total gaze time indicator is the only indicator sensitive enough to detect differences in cognitive processing between professional translators and student translators.

2.2.3 Cognitive resources and source text difficulty in translation

It is generally assumed that the translation of a difficult source text requires more effort than the translation of an easy source text. Indicators that have been used to measure source text difficulty include lexical frequency and readability scores (e.g. Campbell 1999, Jensen 2009). Some of the empirical studies that make observations on source text difficulty in translation include Halskov Jensen (1999), Dragsted (2004), Sharmin *et al.* (2008) and Dragsted and Hansen (2008). These studies are examined in more detail below in relation to the allocation of cognitive resources.

Halskov Jensen (1999)

Halskov Jensen's (1999) study investigated the effects of source text complexity on the translation process. Halskov Jensen used a combination of key logging, TAP, retrospection and questionnaires to elicit process data from four texts, which were translated from Spanish into Danish by six semi-professional[7] translators. Two texts were newspaper articles and two texts were LSP texts (Spanish court judgements). It was hypothesised that the less complex newspaper articles would be easier to translate than the more complex LSP texts. Differences between the two types of text, in terms of processing effort, were identified using measures of reading times and pause duration during text production.

Halskov Jensen found that reading times for the 'easy' newspaper texts were significantly shorter than for the 'difficult' LSP texts. She also found that the number of long pauses (> 4 seconds) was significantly higher in the translations of the LSP texts than in the translations of the newspaper articles. The findings indicate that more cognitive effort is allocated to the translation of a difficult text than to the translation of an easy text. The shorter reading times for the easy texts indicate that the translator is experiencing fewer ST comprehension and TT production difficulties, and the shorter pauses for the easy texts indicate that TUs are processed more quickly and with greater ease. Based on these findings, it may be anticipated that the allocation of cognitive resources in translation is generally affected by text complexity.

Dragsted (2004)

Dragsted's (2004: 103) study, which was also discussed in section 2.2.2, hypothesised that source text difficulty would affect the size of the TU across levels of expertise. She also predicted that professional translators would adopt a more novice-like behaviour during translation of a difficult text than during the translation of an easy text. The two texts that were used in her experiments differed in terms of genre. The 'easy' text was a business letter, which consisted of terms that were expected to not cause many

[7] All Halskov Jensen's participants were final-year students of translation who specialised in translation between Danish L1 and Spanish L2.

translation problems. The ‘difficult’ text was a legal contract, and it was expected that this text would involve terminological problems on the part of both groups of translators.

The results from the translation experiments showed that source text difficulty affected the size of TUs as they were shorter in the translation of the difficult text than in the translation of the easy text. The results also showed that professional translators’ TUs during translation of the difficult text were similar to those of the student translators with respect to size; this was interpreted as a more novice-like behaviour on the part of the professional translators, who, when translating a difficult text, tend to “switch to a more analytic mode of processing” (Dragsted 2004: 239).

With respect to source text difficulty measured by genre type and lexical frequency, Dragsted’s findings support the idea that easy text and difficult text are processed differently. It could be argued that other indicators of difficulty, such as measurements of word frequency, sentence length etc., could have been used to assess the texts’ differences with respect to complexity; overall, however, the findings provide support for the intuition that source text difficulty affects the allocation of cognitive resources in translation.

Sharmin *et al.* (2008)

The study of Sharmin *et al*. (2008), which was discussed in section 2.2.2 above, also investigated the effects of source text complexity on student translators’ eye movements. The three experimental texts of their study were designed to differ with respect to their levels of complexity (measured by word frequency and syntactic complexity). Mean fixation duration and fixation count per minute were used as dependent variables, and changes were taken to indicate a processing effort effect of source text complexity. The analyses showed significantly more fixations per minute during the translation of the two most complex texts (the means were 65 and 67) compared to the least complex text (the mean was 50). Mean fixation durations during ST reading were almost identical (around 210 ms) and showed no statistically significant effect.

The differences in fixation count indicate that more intense processing is involved in the translation of a difficult text than in the translation of an easy text. This observation further supports the intuition that source text complexity affects the allocation of cognitive resources in translation. The findings with respect to fixation duration do not, however, indicate changes in processing effort; on this basis, it is considered likely that fixation count and fixation duration do not reflect the same aspect of cognitive processing. Although more cognitive resources (as indicated by a higher fixation count) are invested in the translation of the difficult texts, the ease/difficulty with which the difficult texts are translated (as indicated by similar fixation duration) is not different from the easy text.

Dragsted and Hansen (2008)

Dragsted and Hansen (2008) used a combination of key logging and eye tracking to collect process data from eight student translators, who translated the same text from L2 English into L1 Danish. The overall purpose of their study was to gain greater insight into how the processes of ST comprehension and TT production are coordinated during translation. They introduced the concept of an *eye-key* span, comparable to the ear-voice span in simultaneous interpreting (ibid. 21), which is measured by observing how much time elapses between the first reading of a given ST word and the moment when typing of its TT equivalent begins. The eye-key span is claimed to be an indicator of problem-solving activity. Longer eye-key spans indicate more processing effort relative to shorter eye-key spans which indicate less processing effort. In the ST translated by the participants, the ST word ‘politically’ was identified as a non-problem word as it has a cognate counterpart in Danish: ‘politisk’; the ST word ‘roadmap’ was identified as a problem word as it does not have a standard Danish translation equivalent. The results revealed that the eye-key span for the non-problem word was between 2 and 8 seconds, while the eye-key span for the problem word was between 39 and 102 seconds.

It does not appear from Dragsted and Hansen’s study if the translator is engaged solely in the translation of this particular problem word or if other words are being processed during the eye-key span of 102 seconds. The study nevertheless provides some indication that the difficulty of an ST word has an effect on the allocation of cognitive resources in translation. More specifically, the translation of a difficult ST word is a more time consuming process, requiring more cognitive resources, than the translation of an easy ST word, which requires comparatively fewer cognitive resources.

With respect to methodology, their study demonstrates a high level of completeness as it applies a *combination* of the methods of key logging and eye tracking. This combination allows them to make stronger inferences about the coordination of comprehension and production processes than if only one method had been used. In the investigation of allocation of cognitive resources in translation, such a combination of non-intrusive online methods is considered to be very useful, as it provides information about the translator’s focus of attention during both typing and reading.

2.2.4 Cognitive resources and time pressure in translation

The relationship between time and interpreting (e.g. Gile 1995, Kohn and Kalina 1996, Pöchhacker and Shlesinger 2002) has received more attention than the relationship between time and written translation. This may be explained by the fact that the issue of time seems much more present in interpreting than in written translation, as the TL message has to be delivered shortly after the ST message has been uttered. In written translation, time does not seem to be an issue to the same extent as in interpreting, and perhaps that is why only few studies have empirically investigated the effects of time pressure on the translation process. In this section, some of these studies are examined; the studies reviewed here are Jensen (2000), Jensen and Jakobsen (2000), de Rooze (2003), all of which relied on data from key logging, and Sharmin *et al.* (2008), which relied on eye-tracking data.

Jensen (Jensen 2000, Jensen and Jakobsen 2000)

In the translation experiments for her PhD thesis, Jensen (2000) had two professional translators, two semi-professional translators and two student translators translate four texts under three different fixed levels of time constraint (15, 20, and 30 minutes). In addition, a warm-up task was translated under a 10-minute time constraint. Key-logging data and TAP data were collected. Jensen's time constraint values were identified on the basis of pilot experiments that were carried out prior to the main experiment. The key objective of her thesis was to investigate to what extent the translation process is affected by time pressure and to investigate which strategies are applied to cope with time pressure.

Overall, Jensen found that the translation process was affected by time pressure as the writing phase received a significantly larger share of the combined production time under time pressure while the revision phase received a significantly smaller share of the combined production time under time pressure. Start-up time was not affected significantly by time pressure. A significant decrease in problem-solving activity during revision was observed when translation was carried out under more restrictive time constraints: the number of problem-solving activities was significantly lower under the 10-minute time constraint than under the 20-minute and 30-minute time constraints. Similarly, significantly fewer corrections were made when the translation was performed under the 10-minute (warm-up task) time constraint than under the 15, 20 and 30-minute time constraints. These observations indicate that time pressure is a factor which affects the translation process, and they provide support for a hypothesis which predicts that the allocation of cognitive resources in translation is sensitive to time pressure.

With respect to the levels of time constraint used in the study, Jensen (2000: 178) points out that most translators in fact had finished their translations before the time ran out under the 30-minute time constraint. The findings from the translations carried out under this time constraint can therefore hardly be considered indication of translation carried out under time pressure. Jensen and Jakobsen (2000: 114) retrospectively proposed that a shorter time condition should have been imposed so that all participants would have experienced time pressure.

An even more restrictive time constraint, for instance at 10 minutes, may well have been experienced as time pressure by all participants. It is, however, also likely that some of the participants would not have experienced the 10-minute time constraint as time pressure. It may be that some participants work extraordinarily fast, and that they are able to finish their translation in 5 minutes, rendering the 10-minute time constraint ineffectual. Although Jensen and Jakobsen call for an even more restrictive time constraint, which would increase the likelihood that all participants experience time pressure, the fixed time constraint approach seems problematic. The fixed time constraint approach rests on the assumption that translators translate more or less at the same pace; this is most often not the case, as translators work at very different paces. In the study of effects of time pressure on the translation process, it should be acknowledged that the experience of time pressure in translation is a highly subjective phenomenon, which is most likely not triggered by the same uniformly administered measure of time constraint. A time constraint approach that takes into account that translators work at different paces is considered a potentially attractive alternative to the fixed time constraint approach, as it is likely to provide data which more objectively reflect the effect of time pressure on the allocation of cognitive resources.

De Rooze (2003)

In his PhD thesis, de Rooze (2003) investigates the effect of time pressure on the translation process and translation quality. De Rooze's participants, who were 30 final-year student translators, translated two texts (around 250 words each) under two levels of fixed time constraint (10 minutes and 15 minutes). There was also a control group of six final-year student translators, who translated under no time constraint. The data collected were key-logging data, using Translog, and questionnaire data. Translation quality was rated by four evaluators (a translation practitioner, a translation student and two translation researchers). The evaluators were asked to fill out questionnaires rating the translation students' products from 1 to 4 (1 = very bad translation, 4 = very good translation) (ibid. 52-53).

Although cautioning that his results should be interpreted tentatively, de Rooze found that under heavy time pressure, translation quality deteriorated significantly. The quality of texts translated under the 10-minute time constraint was more than 15 percent lower than that of texts translated under less time pressure (ibid. 100). De Rooze also noted that some participants, somewhat surprisingly, worked better under heavy time pressure than under moderate time pressure. De Rooze speculates that those participants who work better under heavy time pressure opt for well-known translation strategies and that they apply those strategies more efficiently when they are aware of the limited time available to carry out the translation task (ibid.).

One of the strengths of de Rooze's study is that it bases its findings on data from a large number of participants. 30 participants in the main experiments is a fairly high number in a translation process study, and the large amounts of data collected from the translation experiments enable even stronger conclusions to be drawn compared to studies with a limited number of participants. However, like Jensen's study, de Rooze's study also applied fixed time constraints. Unless all 30 participants worked at more or less the same pace, the results from de Rooze's study should be related to the probability that the individual participants experienced the uniform time constraint differently: a slowly translating participant will have experienced heavy time pressure, while a participant translating quickly will have experienced light or no time pressure. The use of a flexible time constraint would arguably have permitted stronger conclusions to be drawn as it takes into account variability with respect to the speed at which a translator translates.

Sharmin *et al.* (2008)

Sharmin *et al*.'s (2008) study on student translators' eye movements, which was discussed earlier, also investigated time pressure in relation to the translation process. Three levels of fixed time constraint (4 minutes, 5 minutes and 6 minutes) were introduced. Mean fixation duration and fixation count per minute were used as dependent variables.

A slight non-significant decrease in mean fixation duration during ST reading was observed when translating under the most restrictive time constraint; however, the results of the experiment did not reveal statistically significant differences between the levels of time constraint as indicated by mean fixation duration and number of fixations per minute. Nevertheless, the slight decrease in ST mean fixation duration was interpreted as the translators' flexible adaptation of their reading for comprehension processes under increasing time pressure, and the steady TT mean fixation duration across all levels of time pressure was linked to an inflexibility of adapting reading and monitoring processes during TT reformulation (ibid. 47-48).

Sharmin *et al*.'s findings indicate that the cognitive effects of time pressure in translation can be registered using eye-movement based indicators. It is also an interesting observation that it is only cognitive effort allocated to the comprehension of the ST that is affected; the effort allocated to TT reformulation remained largely the same. These observations strongly indicate that ST processing and TT processing constitute two independent subprocesses.

2.2.5 Discussion

Section 2.2 has reviewed empirical studies that consider the relationship between translators' allocation of cognitive resources during the translation process and four factors: processing type, translational expertise, source text difficulty and time pressure. The studies that compared ST processing and TT processing provided general indication that TT processing is a cognitively more demanding task than ST processing. The studies to do with differences in translational expertise indicated that more skilled translators and less skilled translators allocate cognitive resources differently; more specifically, less skilled translators need to allocate more cognitive resources during translation than more skilled translators. The studies which considered source text difficulty indicated that there is a relationship between difficulty and the allocation of cognitive resources. Source texts that were more complex generally required more effort compared to the less complex texts. The studies that considered time pressure indicated, with moderate success, that translators respond differently to time pressure. There was, however, an issue of a methodological nature, which was considered problematic in the investigation of time pressure and cognitive processing in translation: all experiments were carried out using fixed time constraints that were uniform for all participants. Since no two translators are alike, and since no two translators work at the same general speeds, it is very likely that approaches using fixed time constraints are inherently defective since some translators may experience the time constraint as time pressure, while other translators, who work at faster speeds, will not feel the time constraint as time pressure. Studies investigating the relationship between time and the translation process would most likely benefit from using a different type of time constraint, e.g. a flexible time constraint which is designed to match the translation speeds of the individual translator.

Generally, the empirical studies reviewed in this chapter have based their analyses on data from relatively few participants and from relatively few observations. It is possible that larger sets of data, consisting either of more participants or more data points from each participant, would have provided stronger statistical findings in some of the studies.

With respect to the investigation of translators' allocation of cognitive resources in translation, the present study will focus solely on the four factors reviewed above. It is nevertheless acknowledged that other factors may also influence translators' allocation of cognitive resources. For instance, language direction has been found to have an effect on the quality of novice translators' translation products (e.g. Pavlović 2007). In Pavlović's study (ibid. 182), the quality of the translation product was better when translating into the novices' mother tongue than when translating into an L2. There is therefore evidence to suggest that language direction influences translators' allocation of cognitive resources. Another factor that also could have an effect on resource allocation is the use of a translation memory system (TMS). O'Brien (2006a) found that cognitive load (measured by pupil size) is sensitive to the category of translation memory match. In her study, lower cognitive load was registered for exact translation memory matches (100 percent match in terms of linguistic content in the TMS) and higher cognitive load was registered when no translation memory matches were available in the translation memory system (less than 70 percent). Language directionality, using a translation memory system during translation, or other factors, for instance, the availability of offline and online dictionaries are also interesting in relation to translators' allocation of cognitive resources; however, including more variables in this study would complicate the study's statistical design considerably, rendering the analyses extremely difficult. The study will therefore rely only on the four factors reviewed above.

An aim of the review was also to examine the appropriateness of the research methods that have been used to collect translation process data. As illustrated in Toury's quote at the beginning of this chapter, the cognitive processes involved in translation are not available for direct observation. These processes can only be inferred. The relatively novel approach of eye tracking used by Jakobsen and Jensen (2008), Dragsted and Hansen (2008), Sharmin *et al*. (2008) and Pavlović and Jensen (2009) provides a rich set of data though which the researcher can make observations on both the production processes and the comprehension processes involved in translation. Eye tracking provides a more 'complete' set of data than studies which rely on TAP data and key-logging data. In TAP studies, the researcher has to commit herself to instances of verbalisation, and some translation processing might be lost since it is not verbalised. In key-logging studies, the researcher can make strong inferences about the production aspect of translation while less strong inferences can be made about the comprehension aspect of translation. An even stronger approach, as regards completeness, is the one employed by Dragsted and Hansen (2008), as they combine the methods of eye tracking and key logging. In the present study of allocation of cognitive resources, this approach seems particularly useful as it permits the researcher to tap into the comprehension and production aspects of translation more easily than with any of the other methodologies.

Chapter 3

Memory and processes in translation

As noted in section 2.1, the present study considers the translation process a cognitive activity. The study will therefore be based on theories from the cognitive sciences as well as on theories from translation process research. This chapter is divided into four sections: section 3.1 provides a theoretical framework of the human memory system, which is based on research in the general field of cognitive psychology. Section 3.2 identifies and characterises the cognitive processes that are involved in translation. Section 3.3 explores theoretical assumptions and empirical findings that underlie the research methods of key logging and eye tracking which are used in this study to collect data; and finally, section 3.4 provides a summary of assumptions and of the study's hypotheses.

Before starting building the theoretical framework, it is necessary to define two key concepts that are used throughout the chapter and the study in general. The terms cognition and attention are sometimes used interchangeably with reference to the mental activity of *thinking* or *cognitive processing*; in the present study, the two terms are used in different, but related, ways.

Cognition

> (...) cognition refers to all processes by which the sensory input is transformed, reduced, elaborated, stored, recovered, and used. [Cognition] is concerned with these processes even when they operate in the absence of relevant stimulation (...)
>
> Ulric Neisser (1967: 4)

It follows from Neisser's definition that cognition refers to the ability of the mind to process information and to apply knowledge in an information processing setting. For the present study, two terms are defined in relation to cognition: cognitive resources and cognitive processes. Cognitive resources are assumed to be a (limited) pool of mental processing capacity (Baddeley 2003: 835) which may be allocated to a given task through the employment of one or several cognitive processes (Eysenck and Keane 2010: 3). It follows that cognitive processes consume cognitive resources.

Attention

> [Attention] is the taking possession by the mind in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought. It implies withdrawal from some things in order to deal effectively with others (...)
>
> William James (1890: 403)

It follows from James' definition that attention is the activity of allocating cognitive resources to a single piece of information among several, possibly competing, sets of available information. Attention therefore implies an ability to ignore information that is not immediately relevant to a given task, and to focus mental energy on that one piece of information which seems most important to the execution of that task (see also Anderson 2000: 75). It follows from the above definition of cognitive resources and processes that the focussing of attention may draw on one or several cognitive processes while suppressing other cognitive processes.

3.1 The memory system

This section will introduce models and concepts and review research from the general field of cognitive psychology, which are considered to be relevant to the allocation of cognitive resources in translation. The human memory system is generally considered to consist of three overall types of memory: sensory memory (SM), working memory (WM) or short-term memory (STM), and long-term memory (LTM) (Baddeley 1999: 19). A discussion of these memory types along with a discussion of the notion of an attentional controller of WM will constitute a theoretical basis on which relevant hypotheses regarding the allocation of cognitive resources in translation can be developed and evaluated.

3.1.1 Sensory memory

Sensory memory (SM) refers to a theorised system which pre-processes and stores incoming visual and auditory impressions after those impressions have ended. Visual impressions are retained in the iconic memory of sensory memory and auditory impressions are retained in the echoic memory (Eysenck and Keane 2010: 206). A visual impression typically reaches WM after around 60 ms (Jaekl and Harris 2007: 219); the iconic memory, which is central to reading, nevertheless retains information for around 500 ms (Eysenck and Keane 2010: 206).

Not all information that enters SM is forwarded to WM. Several theories suggest that information is filtered so that only relevant information is transmitted to WM (Eysenck and Keane 2010: 154-155). Eysenck and Keane (ibid. 154-158) provide a useful outline of theories that have been put forward with respect to information reduction at the early stages of processing: Broadbent's filter theory (1958) proposes that all sensory information passes through the memory system up until the point a bottleneck is reached. When a bottleneck is reached, information is selected on the basis of certain physical signal properties, e.g. the pitch of a voice, while all other information is ignored. Treisman's attenuation theory (1964) suggests that information is not filtered out entirely on the basis of physical properties, but that the strength of the information signal is weakened so that only nonattenuated information is subjected to conscious processing. The late selection theory (J. Deutsch and D. Deutsch 1963) proposes that there is no capacity limitation on the SM system meaning that all information is relayed to the systems responsible for cognitive processing of the sensory information; the capacity limitation is thus not in the perceptual system but in the response system (e.g. Baddeley's WM system). It will not be considered in this study which of these theories is most plausible, but it is noted that some sort of information filtering occurs. With respect to information filtering and reading, research has demonstrated that processing of a visual impression is automatically activated upon visual exposure; words that are fixated are automatically processed at the orthographic level so that their physical properties (for instance size and contours) are identified before the information is passed on to WM (Valdés *et al*. 2005).

3.1.2 Working memory

Working memory (WM) generally refers to the part of the memory system which is involved in temporarily storing and manipulating sensory input and information from LTM in order to carry out complex tasks (Baddeley 2007: 1). WM is here considered central to the activity of translating as it controls the coordination of several tasks including language comprehension and language production. Drawing on information held within LTM, incoming visual input in the form of ST words is manipulated with the purpose of recreating the SL message in the TL.

The term 'working memory' was made famous by Baddeley and Hitch (1974) with their multi-component model of WM as an alternative to the STM system, as outlined by

Atkinson and Shriffin (1968) in their multi-store model. In Atkinson and Shriffin's model, STM is described as a *passive* storage system in which information is retained for a short moment. Baddeley and Hitch's WM model differs from the STM model as it proposes an account of how information is not only stored but is actively *processed* within the human memory system. Baddeley (2007: 7) highlights this difference as the overall advantage of Baddeley and Hitch's model over an STM model, which "effectively becomes a simple storage model" (ibid.).

Baddeley and Hitch's model was originally a three-part model of WM, but has since been expanded to involve four components: a control system, the *central executive*, and three slave systems, the *phonological loop*, the *visuospatial sketchpad* and the *episodic buffer* (which was added in 2000) (Baddeley 2007: 7-12):

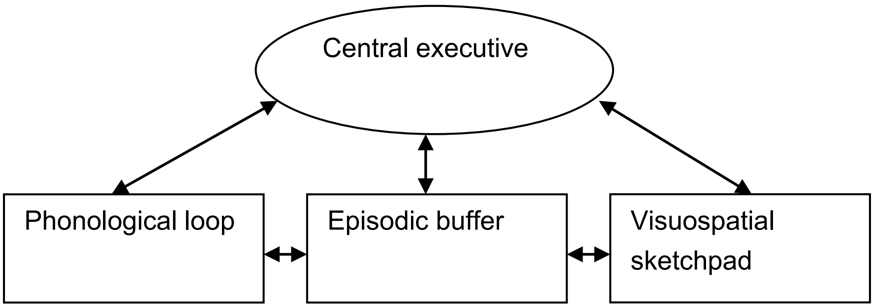

Figure 3a: Baddeley's model of working memory (Figure adapted from Baddeley 2000: 421)

The central executive is an assumed attentional control system that is responsible for coordinating cognitive processing resources (Baddeley 2007: 117). Originally, the central executive was described as a "pool of general processing capacity" or a 'ragbag'-component (ibid. 117-118) into which complex issues that did not appear to be related to the phonological loop or the visuospatial sketchpad could be placed. Aware that this catch-all definition of the central executive was ill-chosen, Baddeley adopted a model of *attentional control* suggested by Norman and Shallice (1986) (ibid.). In Baddeley's adaptation of the model, he distinguishes between two types of governing processes: automatic processes and controlled processes. Automatic, or habitual, processing refers to the central executive's control of processing resources based on habit patterns; automatic processing is assumed to occur *without* conscious awareness. The second type of process refers to the conscious control of processing resources. Often labelled the supervisory attentional system (SAS) (Baddeley 2003: 835), conscious processing intervenes when habit control is insufficient, and thus occurs *with* conscious awareness. During translation, the central executive is responsible for allocating cognitive resources to the processes needed to comprehend the ST and to recreate the message in the TL. The central executive in relation to translation is considered in more detail in section 3.1.4.

The phonological loop (also referred to as the *articulatory loop*) is a subsystem of WM which is concerned with acoustic and verbal information (Baddeley 2007: 8). The phonological loop consists of a passive phonological store, in which acoustic and verbal information is retained for a few seconds, and a rehearsal process, which allows acoustic and verbal information to be refreshed (ibid.). The phonological loop has been found to be involved both in language comprehension (Gathercole and Baddeley 2003: 204) and in language production (Kellogg *et al*. 2007: 394).

The visuospatial sketchpad (also referred to as *visuospatial working memory* and *visual working memory*) is a component of WM which is responsible for temporarily storing and processing visual and spatial information from multiple sources, including the sensory channels (for instance visual information) (see section 3.1.1) and from declarative LTM (see section 3.1.3) (Baddeley 2007: 101). Similar to the phonological loop, the visuospatial sketchpad consists of two sub-components; one which is responsible for storing visual information and another which is responsible for refreshing the visual impression. Research from monolingual text production indicates that the planning process, which involves the organisation of thoughts and ideas, requires access to the visuospatial sketchpad (e.g. Olive 2004: 35 and Kellogg *et al*. 2007: 394). It follows that translation, which is also a process which involves the organisation of thoughts and ideas, also requires access to the visuospatial sketchpad (see sections 3.2.2 and 3.2.2.2).

The original three-part model was unable to account for any exchange and integration of information between the phonological loop and the visuospatial sketchpad, and it was unsuccessful in explaining interaction between WM and LTM (Baddeley 2007: 12-13). To account for these issues, a third slave-system, the episodic buffer, was added to the original WM model in 2000. The function of the episodic buffer is to integrate information from the phonological loop, the visuospatial sketchpad and LTM to form integrated episodes “into a form of temporary representation” (Baddeley 2000: 421). In translation, the episodic buffer is likely to play a critical role in integrating information from ST comprehension and TT reformulation. As will appear from the discussion of WM capacity below, the phonological loop and the visuospatial sketchpad are capable of retaining only a limited number of items for a short period of time. During translation, the translator will typically have to have in active memory much more information than what is held in these two components. The episodic buffer is thus assumed to be a memory component which integrates and temporarily maintains active recent and current translation episodes (i.e. translation units), allowing for those episodes to be recalled from LTM at later stages during the translation.

WM capacity

Being a memory of temporary storage and manipulation, WM is limited in the *amount* of information that can be maintained in a readily available state (e.g. Miller 1956) and by the *time* these items are maintained within WM (e.g. Peterson and Peterson 1959). The ability to control attention may also be considered a measure of WM capacity (e.g. Baddeley 2007) in addition to the two traditional measures of WM capacity. The two former are described below, and the notion of an attentional controller is discussed in section 3.1.4.

With respect to the amount of information held in WM, Miller (1956: 81) suggests that the capacity of STM to retain or channel information is limited to a few items. Miller reports on findings from two types of experiments. The first are from absolute judgement experiments in which participants are instructed to identify and categorise items by assigning numerical values or classifying the items in terms of intensity (e.g. tones that vary in pitch), size (e.g. different-size squares), brightness (e.g. differences in luminance), etc. The second type of experiment involves tests of memory span, in which participants are instructed to repeat a sequence of items (e.g. words, numbers, etc.). Miller found in both types of experiments that STM capacity was limited to between five and nine items (with a recall success rate of 50 percent for seven items).

With respect to the duration of time in which information is held in WM, information decays over time and is completely lost after around 18 seconds if not rehearsed (Peterson and Peterson 1959: 193). Peterson and Peterson carried out a series of experiments in which participants were asked to remember a sequence of three consonants. The participants were asked to recall the sequence after delays of 3, 6, 12, 15 and 18 seconds. Between these delays, interference tasks were given which were intended to prevent the rehearsal of the consonant sequences. Participants' recall success was 50 percent after a delay of 3 seconds and it gradually fell to around 5 percent after a delay of 18 seconds. In other words, information decayed as a consequence of time and interference.

Both types of capacity limitation are expected to have an impact on the translator's allocation of cognitive resources. Throughout the translation process, cognitive processes will compete for access to WM. The task of comprehending the ST will require access to WM as will the task of producing the translation in the TL. Both of these tasks require access to the phonological loop and it is likely that some interference will occur which reduces the amount of information and the time in which this information is held in WM.

3.1.3 Long-term memory

Long-term memory (LTM) refers to a storage system which can retain seemingly unlimited amounts of information for years (Anderson 2000: 205). LTM consists of two types of memory: procedural memory and declarative memory (cf. e.g. James 1890, Eysenck and Keane 2010: 253). The fundamental difference between the two types of memory rests on the distinction between *conscious* recollection from memory and *subconscious* recollection from memory (Eysenck and Keane 2010: 253). Procedural memory is basically a memory of how to perform automatically certain motor and cognitive actions, for instance riding a bicycle, reading, typing, etc. (cf. Baddeley's habitual control in relation to the SAS (see section 3.1.2)). Related to the acquisition and application of those skills (Eysenck and Keane 2010: 272), procedural memory does not rely on consciousness. Skilled bicycle riders, readers, typists, etc. do not have to allocate many WM resources to the performance of those activities, since the knowledge of how to perform them is activated unconsciously. Declarative memory holds information that is available for conscious recollection. Tulving (1972, reported in Eysenck and Keane 2010: 254-255) distinguishes between two types of declarative memory: episodic memory and semantic memory. Episodic memory holds information, such as the memory of an event that took place years ago, and semantic memory holds factual information, such as the meaning of a word.

Both procedural memory and declarative memory are involved during translation. Procedural memory becomes involved when the translator reads the ST and the TT output, and it also becomes involved during typing, which to some extent occurs automatically (see section 3.2.2.3). Declarative memory becomes involved when the translator retrieves the meaning of an ST word during language comprehension and retrieves possible translations of an ST word during language production.

3.1.4 Central executive system

The central executive is considered a limited pool of processing capacity whose role it is to control and coordinate cognitive processing (Baddeley 2007: 117); the central executive is therefore considered to be responsible for the allocation of cognitive resources. According to Baddeley (2007: 120), two overall types of processes are assumed to be controlled from the central executive: automatic processes, which are based on *habit patterns* and *schemata*, and controlled processes, which are activated if habit control is insufficient through a supervisory attentional system (SAS). Baddeley (2007: 124) identifies four capacities, or executive processes: the capacity to focus attention (attentional focus), the capacity to divide attention between concurrent tasks (attentional division), the capacity to switch attention between tasks (attentional switching), and the capacity to integrate information from WM and from LTM (memory integration).

In translation, the central executive is responsible for the efficient allocation of cognitive resources by focussing attention to the relevant subtask (e.g. to ST processing and to TT processing), dividing and switching attention between these subtasks and combining incoming visual information with procedural and declarative knowledge from LTM. The former three capacities are considered below, while the capacity to integrate from WM and LTM was considered in relation to the outline of the episodic buffer in section 3.1.2, above.

3.1.4.1 Attentional focus

Attentional focus refers to the capacity of the central executive to allocate the limited pool of WM processing resources to one particular task by inhibiting potentially interfering information and to maintain processing resources allocated to that particular task for as much (or little) time as necessary (Baddeley 2007: 193). Baddeley (ibid.) considers Allport *et al.*'s (1972) example of expert pianists who are able to engage successfully in a dual-task setting (see section 3.1.4.2, below). Here, this example is considered, but with emphasis on the sustained focus of attention to one task. The expert pianist is capable of reading musical scores and pressing the correct piano keys at the same time. During piano playing, the skilled pianist focuses attention on the task which is most necessary at a given point (score reading or playing), and switches the focus of attention to the other task when needed until the piano piece is finished. Successful piano playing therefore implies a high capacity to control attention and to optimally alternate the allocation of cognitive resources between the two tasks. If the pianist reallocates cognitive resources from one task to the other too early or too late, the pianist may miss keys or press the wrong keys. As Baddeley states, the capacity to maintain attentional focus is closely related to expertise (ibid. 124), and it follows that a less skilled pianist will make more mistakes.

Translation is also a dual-task activity as it involves at least the two tasks of comprehending the ST and reformulating the TT. These two tasks compete for attentional focus as they require cognitive resources to be allocated either to language comprehension or to language production. ST comprehension must be sustained long enough for a translator to arrive at a plausible meaning hypothesis (cf. Gile 1995), and TT reformulation must be sustained long enough for the translator to identify a TL rendition of the extracted ST meaning. This means that if ST processing is terminated prematurely, then the translator may not have arrived at a plausible meaning hypothesis, and if TT processing is terminated prematurely, then the translator may not have identified a translation equivalent in the TL.

Considering differences in translational expertise, a skilled translator will be more successful than a less skilled translator in allocating cognitive resources in a manner which facilitates translation. More specifically, the skilled translator will be better than a less skilled translator at focussing attention and thus cognitive resources on relevant comprehension and production processes for as long or as little time as necessary.

With respect to translating a difficult text, it is likely that a translator's attention is focussed on ST comprehension for longer compared to when she is translating an easy text since more time is needed to arrive at a plausible meaning hypothesis. Similarly, attention is focussed on TT reformulation for longer since more time is needed to identify a translation equivalent.

During translation under time pressure, it is also likely that a translator's attention is focussed on ST comprehension and TT reformulation for shorter periods of time because less time is available to establish meaning hypotheses and to identify translation equivalents.

3.1.4.2 Attentional division

Another capacity of the central executive is the ability to divide attention between tasks that are carried out in parallel (Baddeley 2007: 133). Attentional division, i.e. the splitting of attention between two or more tasks, is involved in many activities, for instance during driving, during sports, etc. During driving, the driver has to be attentive to other cars, traffic lights, pedestrians etc. in order to avoid accidents, and during a football match, the football player has to pay attention to the ball as well as to the other players. These activities require an ability to respond to several tasks.

Turning to the example of the expert pianist, who is capable of optimally alternating her allocation of cognitive resources between two competing tasks, it might be that she divides her attention between the two tasks of score reading and piano playing. According to Baddeley, this should be possible as "both of these tasks could (...) be run using highly practised existing schemata, which can be interleaved with relatively little demand on the SAS" (Baddeley 2007: 124). It follows that one process occurs relatively unconsciously, resting on habit patterns, while another process is controlled and at the centre of attention.

With respect to the case of translation, it could be argued that the translator attends to the demands of ST processing and TT processing at the same time. One process therefore occurs automatically and the other process occurs consciously. For instance, while trying to construe the meaning of an ST word, the translator engages in automatic, habitual TT typing, or during automatic, habitual ST reading, the translator engages in conscious TT reformulation. Since the capacities to focus and divide attention are closely related, it is likely that expertise also plays a role in the capacity to divide attention. A skilled translator is better at splitting her attention between several subtasks of translation than a less skilled translator, who cannot rely on the same habit patterns and schemata.

3.1.4.3 Attentional switching

Attentional switching refers to the mental activity of reallocating WM processing resources from one task to another. There is evidence from experiments within the field of cognitive psychology which suggests that the switching of attention between tasks incurs some cognitive cost in the form of increased processing times (Baddeley 2007: 130-132). This cognitive cost has been found to be sensitive to task complexity and expertise such that higher attention switching costs were identified in difficult tasks and higher attention switching costs were identified for persons who were less experienced with a given task (ibid.).

Translation, being a dual-task activity, inherently involves switching attention between ST processing and TT processing. The frequent shifts between ST processing and TT processing are expected to incur some cognitive cost. In a study that investigated eye movements across different reading tasks, one of which was translation, Jakobsen and Jensen (2008) (see also section 2.2) found that translators shifted their focus of visual attention between the ST and the TT every three to four seconds. In addition, it was found that the number of fixations in tasks that involved reading while typing a translation significantly exceeded the number of fixations in tasks that involved reading for comprehension. One contributory factor to the increase in fixations was thought to be "the confusion and disorientation caused by frequent transitions between [the ST and the TT]" (ibid. 120). Following these findings, there is some indication that the cost of switching attention in translation is cognitively demanding; considering Baddeley's comment that the cognitive cost of switching attention is related to expertise, it follows that the cognitive cost of switching attention will be higher for less skilled translators than for skilled translators.

Overview of the central executive system

The notion of an attentional controller provides a theoretical framework for investigating translators' allocation of cognitive resources. It will be helpful in interpreting translators' responses to the demands of language comprehension and language production, source text difficulty and time pressure. It is proposed here that a translator's employment of central executive processes, as indicated by shifts in attention, is indicative of her management of cognitive resource. With respect to the case of interpreting, it has already been pointed out that good management of cognitive resources is very important and that it is a skill which is developed through practice (Gile 1995: 186-187). *Capacity management*, in Gile's terminology, refers to "allocating and shifting processing capacity between the various Efforts" and "good capacity management (...) is important for interpreting" (ibid. 186). Although written translation does not impose the same demands for instantaneous delivery of the translated message as does interpreting, optimal management of cognitive resources is nevertheless likely to be an aim also for translators, who will seek to make the most of their limited cognitive resources.

3.2 Processes in translation

From a cognitive perspective, the translation process is often considered to consist of two types of processing: ST processing (sometimes also referred to as ST comprehension) and TT processing (sometimes also referred to as TT reformulation or TT production) (see also section 2.1). The traditional dichotomous distinction between ST processing and TT processing nevertheless falls short of accounting for the complexity of the translation process from a cognitive perspective. The discussion of the human memory system in section 3.1 provided some basis for subdividing further the processes involved in translation. A more finely granulated account of the processes involved in translation will be relevant in interpreting how translators allocate cognitive resources. Based on research in general language comprehension and written language production, this section will identify and outline some of the subprocesses of ST processing and TT processing and relate these subprocesses to the discussion of the human information system in section 3.1.

Before looking into the cognitive processes involved in translation, a relevant distinction is considered between the different production stages of translation. The translation process is generally considered to consist of several production stages or phases during which different tasks are carried out (e.g. Mossop 1998, Jakobsen 2002). Mossop (1998: 40) divides the production of a translation into three phases: *pre-drafting*, which takes place before sentence-by-sentence drafting begins, *drafting*, which involves the composing of the translation, and *post-drafting*, which takes place after sentence-by-sentence drafting is completed. These phases are similar to the stages identified by Jakobsen (2002: 90-91), who labels them the *orientation* stage, the *drafting* stage and the *end revision and monitoring* stage. According to Jakobsen's operationalisation criteria, the orientation stage begins when the translator is presented with the ST and ends with the typing of the first text production keystroke. The drafting stage begins immediately after the orientation stage and ends when the translation of the last ST sentence is completed as indicated by the typing of the final full stop. The end revision and monitoring stage begins immediately after the typing of the final full stop and ends when the translator decides that the translation has been completed. In a translation experiment (ibid. 92) which aimed at identifying how much time is spent on each stage, eight translators were asked to translate a number of texts. Jakobsen found that the amount of time allocated to each of the three production stages was different: the amount of time allocated to the orientation stage was around 2-3 percent, the drafting stage was around 77 percent and the revision stage was around 20-21 percent.

During each of the three stages of translation, different goals and objectives are arguably pursued. In the orientation stage, the overall goal is to get familiarised with the ST. During drafting, the overall goal is to create a translation of the SL message in the TL. During revision, the overall goal is to verify that the drafted translation meets the quality criteria as defined by the translator, and possibly also to perform corrections. Although no empirical studies have compared differences in cognitive processing effort between the three stages, it would not defy logic to assume that processing effort is different between stages since the underlying goals are different. Assuming that processing effort is identical across all three production stages entails the risk of basing an analysis on data that reflect several tasks. Since the object of interest in the present study is the allocation of cognitive resources devoted to *translation*, the discussion on ST processing and TT processing below, and as such the study's empirical analyses, will focus on the processes involved in the stage of translation which involves the majority of translation, i.e. the drafting stage.

3.2.1 ST processing

The review and discussion of the human memory system in section 3.1 make it possible to distinguish between two subprocesses of ST processing: ST reading and ST comprehension. Often used synonymously, ST reading and ST comprehension could be argued to be two sides of the same coin: ST reading in translation (hopefully) leads to comprehension of the ST, and comprehension of the ST presupposes that the ST has been read at one point. However, from a cognitive psychological perspective, ST reading and ST comprehension are two very different processes. ST reading (i.e. the perceptual decoding and the highly transient storage of words or strings of words) is an activity which involves SM alone, while the process of extracting and reconstructing meaning from an ST message (i.e. the process of comprehending) is an activity which involves WM and LTM. Partition of the subprocesses and levels of processing involved in language comprehension has been suggested in cognitive psychology and translation process research (e.g. Kintsch 1988, Danks and Griffin 1997, Padilla *et al*. 1999 and Anderson 2000). For instance, Anderson (2000: 389) identifies three stages (not to be confused with Jakobsen's translation stages outlined above) that make up language comprehension: the first stage consists of the perceptual processes, which are the processes that are involved in decoding visual information; such a stage is reading. The second stage is the parsing stage. During parsing, meaning is constructed through processes of semantic, syntactic, phrasal etc. analyses. In the third stage, which Anderson labels the utilisation stage, the reader or listener acts upon the newly obtained information. Although not an integral part of the comprehension process, Anderson probably includes the utilisation stage to illustrate that information is rarely passively recorded, but that the newly obtained information in fact generates some form of action on the part of the recipient (ibid. 406). Padilla *et al.* (1999: 63) suggest a more detailed account of ST processing in their proposal for a cognitive theory of translation and interpreting. They identify five levels of processing that are involved in comprehending an ST message. These are:

(1) orthographic or phonological analyses of the sensory input; this level of processing precedes actual comprehension;
(2) lexical and semantic analyses are performed, during which a meaning of the word is identified;
(3) segmentation of the text or discourse is carried out, in which propositional relationships are formed between the words;
(4) a propositional structure of the identified propositions is created which draws on LTM;

(5) 'a higher level representation' is constructed which involves the elimination of propositions of lesser importance.

Padilla *et al*. point out that the model should not be interpreted as a serial account of comprehension. They state that both bottom-up processing and top-down processing occur; bottom-up processing proceeds from sensory input to the meaning representation of the text, and top-down processing proceeds from the meaning representation of the text to sensory input (Padilla *et al*. 1999: 63). This means, for instance, that lower levels of processing may be affected by higher levels of processing (e.g. the higher level representation will have an impact on lexical and semantic analyses, since a word belonging to the same domain may trigger a specific meaning of a new word being analysed).

Levels 2, 3 and 4 of Padilla *et al*.'s model are based in some degree on Kintsch's (1988) construction-integration model. Kintsch's model provides a more detailed account of the creation of propositions during comprehension than that of Padilla *et al*. In its most basic form, a proposition is a logical relationship between two words which together form a unit of meaning (e.g. Kintsch 1998: 37). For instance, the sentence "the new car was stolen" consists of two propositions: (i) the car is new, and (ii) the car was stolen. Considered separately, the words 'new', 'car' and 'stolen' do not convey contextual meaning; together, however, they represent units of meaning. As the name of the model implies, construction-integration involves first a construction phase, consisting of levels 1 and 2, and then an integration phase, consisting of levels 3, 4 and 5:

(1) propositional relationships between words in the text itself are constructed;
(2) these text-based propositions then retrieve related propositions from LTM;
(3) the propositions that are highly interconnected with other propositions are selected, while irrelevant propositions that are not highly interconnected are discarded;
(4) a text representation of the selected propositions is stored in what Kintsch calls the *episodic text memory*;
(5) once inside the episodic text memory, the text representation is transferred to LTM from which it becomes available for future comprehension processes.

Unlike Padilla *et al*.'s model, the levels of Kintsch's model occur serially in a bottom-up manner (Eysenck and Keane 2010: 407). This means, for instance, that the creation of text-based propositions precedes the creation of LTM-based propositions.

Table 3a summarises the stages and levels that are involved in comprehension, according to the views of Andersen, Padilla *et al*. and Kintsch:

Table 3a: Processing stages and levels during comprehension

ST processing		
Anderson	Padilla *et al.*	Kintsch
Perceptual analysis	Orthographic or phonological analysis	
Parsing	Lexical and semantic analysis	
	Propositional relationships	Text-based propositions
		LTM-based propositions
	Propositional structure	Propositional selection and discarding
	Propositional representation	Text representation of selected propositions
		LTM transfer of text representation
Utilisation	*(for instance TT processing)*	*(for instance TT processing)*

In part based on the views of Andersen, Padilla *et al*. and Kintsch, the following sections propose two central subprocesses and levels of processing which make up ST processing in translation, cf. Table 3b. The proposed account is intended to provide a general outline of the levels of ST processing, which will serve as a framework for evaluating the study's hypotheses to do with translators' allocation of cognitive resources. The outline is *not* intended to serve as an accurate description of the nature of ST processing in translation. The outline may, however, provide a basis for the development of a more extensive model of language comprehension in translation.

Table 3b: Subprocesses involved in ST processing

Subprocess	***Levels of processing***
ST reading	Orthographic analysis
ST comprehension	Lexical analysis
	Propositional analysis
	Text representation and LTM transfer

In this proposed account, ST reading involves orthographic analysis and ST comprehension involves lexical analysis, propositional analysis and the creation of a text representation and LTM transfer of this text representation. Notwithstanding that both bottom-up and top-down processing occur in translation, it will not be considered in more detail here to what extent bottom-up and top-down processing affect ST processing.

3.2.1.1 ST reading

The goal of ST reading is to extract relevant information which is to be translated. When an ST word has been fixated, the physical properties of its letters are identified and forwarded to WM. The pre-processed word becomes available for cognitive processing in WM after around 60 ms (see section 3.1.1). In the present study, it is assumed that only low cognitively demanding pre-processing of incoming information occurs during ST reading.

3.2.1.2 ST comprehension

During ST comprehension, the translator engages in lexical analysis in order to identify the meaning of an ST word (Padilla *et al*. 1999: 63). This analysis involves the phonological loop of WM (see section 3.1.2) and LTM (see section 3.1.3). With respect to the case of translation, there is evidence to suggest that potential TT equivalents of ST words are identified in parallel with this process (Ruiz *et al.* 2008: 491), and there is also evidence that syntactic processing of the TT occurs at an early stage in parallel with ST comprehension (Jensen *et al*. 2009: 331) (see section 3.2.4.2 for a discussion of parallel processing in translation).

When the meaning of an ST word has been identified, propositional analysis is performed in order to create a meaning representation of the ST. For reasons of simplicity, the proposition steps of Kintsch's construction-integration model are grouped together here so that propositional analysis essentially involves: (1) formation of text-based propositions, (2) retrieval of related propositions from the episodic buffer of WM (cf. Kintsch's episodic text memory) and from LTM, and (3) selection of relevant propositions and deletion of irrelevant propositions. During translation, propositional analysis is arguably guided by the goals that the translator considers relevant in order to comprehend the text. It is a reasonable assumption to make that *different* goals are being pursued during propositional analysis for translation than during propositional analysis for 'normal' comprehension. With respect to Gile's notion of a meaning hypothesis (1995: 102-105), it is reasonable to assume that the meaning hypothesis the translator establishes for a given ST segment will be based on differently filtered propositions than had a sentence been read for a different purpose. The propositions that are constructed during comprehension for translation in steps 1 and 2 are most likely similar to those constructed during ‘normal’ comprehension; however, the selection and deletion of *relevant* propositions is most likely different for comprehension for translation than for normal comprehension. Since the translator will have to convey the meaning of the ST to the greatest extent possible, it is argued here that many more *relevant* propositions are placed in the text representation. In this context, it is proposed that the placement of propositions in LTM incurs some cognitive cost in the form of an increase in time consumption as the placement of more propositions requires more time. This assumption is supported by evidence from reading experiments by Jakobsen and Jensen (2008: 109-111) (see also section 3.3.1.1), which show that reading for translation is more effortful than reading for normal comprehension. Finally, a representation containing all the propositions from this analysis is stored in LTM from which it is available for future propositional analyses through the episodic buffer of WM.

3.2.2 TT processing

TT processing is often considered as one monolithic process which is contrasted with ST processing. Within the context of a human memory system, it is problematic to consider TT processing as a single process, since different memories are involved at different points throughout TT processing. This section will offer a proposal of the subprocesses that make up TT processing.

Kellogg’s (1996) model of monolingual text production proposes an account of the processes that are involved in the writing process. Three groups of subprocesses are identified, each of which comprises two levels of processing: (1) formulation (comprising planning and translating[8]). During planning the writer will "(...) construct a pre-verbal message that corresponds to the ideas a writer wants to communicate. In this stage, ideas are retrieved from long-term memory (...)" (Olive 2004: 32). In other words, during planning the writer *plans* her goals and ideas, drawing on LTM, and she *translates* (i.e. encodes) those goals and ideas lexically and syntactically in her mind. (2) The second group of subprocesses is execution (comprising programming and executing). During execution the writer *programs* and instructs the motor systems to *execute* the writing event (e.g. a typing event). (3) Finally, the third group of subprocesses involves monitoring

[8] Kellogg’s use of the term ’translation’ refers to the mental generation of a linguistic representation of a meaning unit during the process of language production. Kellogg’s use of the term ’translation’ is thus different from the one used throughout the present study, in which ’translation’ refers to general transfer of meaning units from one language to another.

(comprising reading and editing) during which the writer *reads* her text and performs *edits* (Kellogg 1996). All three subprocesses, according to Kellogg's model, involve the central executive, the phonological loop and the visuospatial sketchpad,[9] with the exception of executing typing events, which does not occupy WM resources (e.g. Kellogg *et al*. 2007). During formulation, planning involves the central executive and the visuospatial sketchpad in the creation and organisation of ideas. Translation (i.e. encoding) relies on the phonological loop as well as on the central executive in translating the ideas semantically and syntactically (Olive 2004: 35). With respect to monitoring, this also involves the phonological loop as well as the central executive (ibid. 62).

In this study, Kellogg's model of the writing process forms the basis for three subprocesses, which are proposed to be involved in language production during translation, cf. Table 3c. The three subprocesses are: TT reformulation,[10] which is comparable to Kellogg's formulation subprocess, TT typing, which is comparable to Kellogg's execution subprocess, and TT reading, which is comparable to Kellogg's monitoring subprocess. As with the outline of the subprocesses of ST processing, the aim of this proposed account of TT subprocesses is to provide a general outline of TT processing which will be used to evaluate the study's hypotheses to do with translators' allocation of cognitive resources during the translation process. This outline may also provide a basis for the development of a more comprehensive model of language production in translation.

Table 3c: Subprocesses involved in TT processing

Subprocess	***Levels of processing***
TT reading	Orthographic analysis
TT reformulation	Planning Encoding Verification
TT typing	Programming Executing

[9] At the time Kellogg presented his model in 1996, Baddeley and Hitch's original model only consisted of the central executive, the phonological loop and the visuospatial sketchpad. The episodic buffer was not added until 2000.

[10] The present study uses Gile's term 'TT reformulation' in place of Kellogg's term 'formulation'. Gile's term illustrates better that translation involves the *transfer* of a message from one language into another. Alternatives inspired by translation process research include 'TT processing' and 'TT production'. In the context of the present study, these are nevertheless considered inadequate; the former is considered too broad, and is used already to characterise all the subprocesses involved in language production during translation; the latter is considered too narrow in the sense that it could be (mis)-interpreted as relating solely to the operation of typing a translation.

In this proposed account of the subprocesses of language production during translation, TT reading consists of orthographic analysis of emerging and existing TT output; TT reformulation consists of planning, encoding[11] and verification; and TT typing consists of programming and executing. The three subprocesses are not necessarily processed in a serial manner as illustrated in Table 3c, and they are not interdependent to the same extent as the subprocesses involved in ST processing. It is nevertheless assumed that TT reformulation precedes TT typing and that ST comprehension precedes TT reformulation. TT reading precedes the verification level of TT reformulation.

3.2.2.1 TT reading

The goal of TT reading is to extract information from text that has already been translated. It is presumed that, for the most part, the underlying goal of TT reading during translation has to do with verification of TT output which is being typed or which has been typed. Two types of TT reading are therefore considered: reading of *emerging* TT output and reading of *existing* TT output. Both types of reading indicate that the translator is engaging in verification of the TT output as part of the reformulation process (see section 3.2.2.2 below). TT reading, unlike ST reading, is not a precondition for translation; a translator is free to translate without ever glancing at the TT, which in essence makes TT reading a facultative process. It is probably unlikely, however, that translators do not engage in TT reading at some point during translation drafting.

With respect to orthographic analysis of letters and words, TT reading is not different from ST reading. TT reading also involves orthographic analysis of the word's physical properties, such as size, contours etc., and it is assumed that the word becomes available for cognitive processing after around 60 ms (see section 3.1.1). It is also assumed that only low cognitively demanding pre-processing of incoming information occurs during TT reading.

3.2.2.2 TT reformulation

In the proposed model, TT reformulation follows immediately after the creation of a text representation of the ST message. The point at which ST comprehension ends and TT reformulation begins is probably not as categorical as indicated here, since it is possible

[11] The process of *encoding* during TT reformulation that is defined here is considered to be similar to Kellogg's process of *translating*. The term *encoding* was chosen instead of *translating*, as the latter could lead to some confusion in the present study.

that TT reformulation in fact begins much earlier, for instance during lexical or propositional analyses, so that ST processing and TT processing in fact overlap (see section 3.2.4.2 for a discussion on parallel processing during translation). Here, it will not be considered in more detail at what point TT reformulation begins; rather, the focus is on characterising TT reformulation as a subprocess during which the TT message is created irrespective of process overlap.

Similar to Kellogg's model of writing, reformulation during translation also involves *planning* and *encoding*. More specifically, during *planning*, the translator retrieves the text representation, which was created during ST propositional analysis, and then *encodes* the retrieved text representation in the TL syntactically and lexically. The phonological loop, the visuospatial sketchpad and the central executive are all involved during reformulation.

As established above, the translator engages in TT reading in order to perform *verification* tasks on the TT such as checking spelling and punctuation and making sure that the ST meaning has been transferred as intended. The nature of the verification tasks that are indicated by each of the two types of TT reading are likely to be different: during reading of emerging TT output, micro-level verification tasks, such as checking spelling and punctuation are performed. During reading of existing TT output, macro-level verification tasks, such as checking for sentence coherence, checking for agreement between ST meaning and TT meaning etc. are performed, in addition to micro-level verifications tasks. Irrespective of the type of verification that is indicated by TT reading, the present study considers verification tasks to be a part of the TT reformulation process.

3.2.2.3 TT typing

Similar to the execution processes of Kellogg's model, TT typing and the processes of programming and executing involve turning the linguistic representation that was formed during TT reformulation into actual typing events. During programming, the translator instructs the motor systems to *execute* typing events, and these typing events are then performed more or less automatically without much involvement of WM as typing relies on fixed schemata (see section 3.1.4). Experiments have demonstrated that typing can become automated through repetition (i.e. through practise) (Spelke *et al*. 1976, reported in Anderson 2000: 99). In a dual-task paradigm, two subjects were trained over the course of six weeks to copy unrelated words at dictation while simultaneously reading for comprehension. In the beginning of the experiment, reading speeds were considerably slower, indicating that the typing task occupied processing capacity that would otherwise have been allocated to the comprehension task. At the end of the six-week period, reading speeds had increased and reached normal reading speeds. Spelke *et al.* concluded that the subjects had developed an ability to perform copy typing automatically which did not interfere with the WM processing demands involved in reading for comprehension. Salthouse (1986) reports on a similar study on transcription typing, in which 29 typists read a text and typed that text's letters and words. Salthouse found that the typists were unable to account for the content of the text they had just typed. Salthouse (1986: 309) proposes that one explanation is that the process of transcription typing is highly automated and that it therefore is not cognitively demanding.

These studies provide support for assuming that the central executive of WM is involved only to a limited extent in typing during translation. It may nevertheless be that executive control processes of the central executive override these fixed schemata that govern typing in case unusual typing is required. For instance, commands that involve multiple simultaneous keystrokes, typing events that involve infrequently used characters to be typed, etc. In these situations, typing would occupy WM. However, typing is here considered to be an activity in which translators, for the most part, engage more or less automatically, i.e. without the involvement of executive processes.

3.2.3 Automatic processing in translation

Automated processes are generally considered to be those operations which are maintained without conscious control and which require no or few processing resources (e.g. Anderson 2000: 98). Processes are often automated as the result of task repetition, for instance riding a bicycle, driving a car, reading etc. (Anderson 2000: 98), drawing on procedural LTM (see section 3.1.3). These tasks require intentional initiation in some form, but their continuity is supported by subconscious processing since a driver or a reader does not have to consciously allocate processing resources to maintaining the activity.

In translation, which involves the obligatory processes of ST reading, ST comprehension, TT reformulation and TT typing and the facultative process of TT reading, it may be expected that some automatic processing takes place. Processes which involve orthographic analysis during ST reading and the mechanical operation of TT typing, as defined in sections 3.2.1 and 3.2.2, do not require conscious processing. These two operations are partly automated. Although the translator intentionally initiates the reading process by moving her eyes to the location of the word, visual exposure to the letters activates an orthographic processing stream (see sections 3.2.1.1 and 3.2.2.1) and an automatic bottom-up processing stream which cannot be interrupted (Valdés *et al*. 2005:

279). With respect to typing, there is also evidence to suggest that the action of typing may become partly automated, as discussed in section 3.2.2.3.

In translation, it is unclear if and to which extent (elements of) the translation process is automated. Jääskeläinen and Tirkkonen-Condit (1991) compared data from four student translators' and three professional translators. They predicted that professional translators would engage in more automatic processing than student translators. They found that professional translators spent less time producing TL segments than student translators, which was interpreted as evidence of more automatic processing on the part of the professional translators. Dragsted (2004: 47) appears to take the opposite stance and argues that the translation process is an inherently non-automated process in that it always involves activation of WM. She notes that the translator constantly has to construe the meaning of the ST or reformulate it in the TL (ibid.).

The findings from Jääskeläinen and Tirkkonen-Condit's study and Dragsted's claim seem to contradict each other. However, they differ in their methods of measuring automaticity. In Jääskeläinen and Tirkkonen-Condit's study, the translator's capacity to engage in automatic processing was measured by the speed with which a translation unit was processed. Their usage of the term automaticity is therefore not necessarily synonymous with complete disengagement of conscious cognitive processing, but could more easily be interpreted as a change in workload on WM. The point of departure in Dragsted's claim is one which relates automaticity to WM. It follows from Dragsted's claim that the translation process will always be non-automated since a task relevant to the translation will always occupy the translator's WM. Automaticity in translation can therefore never occur, according to Dragsted.

The two stances are not as mutually exclusive as would initially appear as they measure automaticity differently. In translation process research, there seems to be no collective agreement on how automaticity during translation should be measured. From a process-oriented cognitive perspective, Jääskeläinen and Tirkkonen-Condit's time measurement unit is problematical in that any reduction in the amount of time spent translating should not be straightforwardly equated with activation of automatic processing; the reduction in the amount of time might as well be explained by the fact that the translator simply processes the translation faster. Dragsted's rejection of automaticity in translation also seems questionable, however, at a more finely granulated level of WM processing. Dragsted implicitly assumes that during translation, conscious processing relevant to the translation task will always occur. This is a reasonable starting point; however, she does not consider automaticity in relation to the *subprocesses* of translation which may occur automatically, for example automatic ST reading and automatic TT typing. As noted earlier in this chapter, there is evidence that some of these subprocesses could occur automatically without demanding (many) WM resources.

In the present study, which investigates the allocation of cognitive resources during translation, automaticity is defined within the narrow confines of cognitive psychology. Automaticity is defined as the sustention of one (or more) processes with little involvement of WM executive processes. This theoretical possibility of automatic processing supports a hypothesis which states that parallel processing is possible during translation since ST processing and TT processing could co-occur at the same time. Another parallel processing hypothesis may also be proposed, which predicts that parallel processing incurs relatively higher cognitive load compared to ST processing and TT processing, because attention needs to be split between two tasks. However, a counter-argument against this hypothesis could be that automatic processes generally do not demand very many processing resources and that cognitive load during parallel ST/TT processing is not a function of combined ST processing load and TT processing load. In section 3.2.4 below, the matter of serial processing versus parallel processing in translation will be examined as three views are presented of how the two tasks of ST processing and TT processing are coordinated.

3.2.4 Coordinating ST processing and TT processing

This section will consider theoretical views of how ST processing and TT processing are coordinated during translation. The views examined below will be related to the discussion of the memory system in section 3.1, with some focus on Baddeley's model of WM, and to the subclassification of cognitive processes in translation discussed in the first part of section 3.2.

Gile's sequential model of the translation process, which was reviewed in Chapter 2, suggests that the translation process consists of consecutively arranged cognitive phases (i.e. ST comprehension phases and TT reformulation phases) or *processing building blocks*. Gile's model implicitly assumes that these building blocks occur successively; however, as the discussion throughout the present chapter has indicated, it seems that it is possible that ST processing and TT processing in fact overlap. There are three competing views of how the translation process is coordinated. The first view is the sequential view (e.g. Seleskovitch 1976), which proposes that the building blocks follow in immediate succession of one another, without overlap of ST processing and TT processing. The second view of the translation process proposes that the building blocks overlap, constituting the parallel view (e.g. de Groot 1997) of the translation process. The third view, the hybrid view (Ruiz *et al*. 2008: 490), suggests that the translation process consists of both sequential processing and parallel processing so that the composition of building blocks alternates between ST and TT building blocks that follow in succession of each other and ST and TT building blocks that overlap each other.

3.2.4.1 Translation as a sequential process

The *sequential* view (also referred to as the *vertical* view (de Groot 1997: 30)) of the translation process argues that full comprehension of the SL message must be achieved before any rendition of the message in the TL can begin (ibid.). By her deverbalisation theory, Seleskovitch (1976: 94) proposed that during translation, the SL message is first dissolved into a mental representation without linguistic form during comprehension. When comprehension is finished, the deverbalised message is reconstructed in the TL. Seleskovitch's deverbalisation theory was originally intended to account for cognitive processing in interpreting. However, it has been treated as a model of sequential processing in written translation as well (e.g. de Groot 1997, Macizo and Bajo 2004, Ruiz *et al.* 2008 and Jensen 2011).

In the sequential view, comprehension of ST lexis, syntax and discourse are processed independently before TL production begins (Macizo and Bajo 2004: 183). It might be interpreted from the sequential view that ST processing is not different from normal language comprehension (cf. Figure 3b below). Composition of the TT and the considerations that relate to the pragmatic function of the TT, the choice of lexical elements and the syntactic arrangement take place only when ST comprehension is completed.

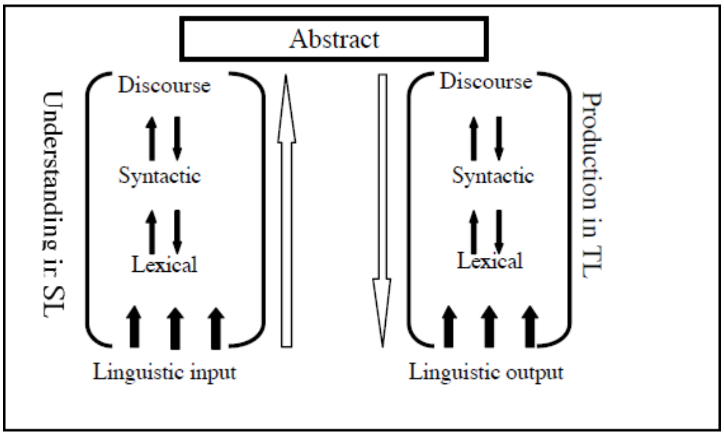

Figure 3b: Sequential processing during translation (from Macizo and Bajo 2004)

Seleskovitch does not substantiate the deverbalisation theory empirically; instead she bases her argumentation on experience as a practitioner of interpreting (Gile 1997: 90). The raison d'être of the sequential view has to some extent rested on the observation that a translated text (or an interpreted message) sometimes has little lexical and syntactic resemblance to the ST (Mossop 2003). In recent years, the sequential view has been target of some criticism; experiments have demonstrated that TL processing is in fact activated at the early stages of comprehension (see section 3.2.4.2, below). Seleskovitch, however, does not claim that the translation (and interpreting) process is an exclusively sequential process. She acknowledges that parallel processing takes place to some extent in interpreting and more so in written translation, but she contends that sequential processing dominates both interpreting and written translation (1976: 94). Although empirical studies have tended not to favour the sequential view but rather the parallel view, Gile (1997: 90) offers some support for it by emphasising that it is useful for didactic purposes; however, he notes that its main shortcoming in particular is its lack of empirical support.

3.2.4.2 Translation as a parallel process

The parallel view of the translation process proposes that ST comprehension and TT reformulation occur simultaneously (e.g. Gerver 1976). Linguistic SL features are replaced by equivalent TL features more or less instantaneously as reformulation of the TT begins without delay as soon as the translator engages in ST comprehension (Ruiz *et al.* 2008: 491). The parallel view therefore holds that ST comprehension during translation is different from normal monolingual comprehension since TL processing coincides with SL comprehension and therefore affects SL comprehension. The parallel view is also described as horizontal translation (de Groot 1997: 30). De Groot notes that "[the] horizontal translation [view] construes translation as transcoding, that is, as the replacement of SL linguistic structures of various types (words, phrases, clauses) by the corresponding TL" (ibid.).

A proponent of the parallel view is Mossop who argues that: "both [comprehension and production] processes (...) occur simultaneously and they do so whenever someone is translating. It is never a case of one or the other. (...) at the same time [simultaneously], the translator's bilingual brain automatically produces TL lexical and syntactic material based on the incoming SL forms and on the connections (...) between TL and SL items in the mental store of language knowledge" (Mossop 2003). The model in Figure 3c below illustrates that switching between ST processing and TT processing occurs at a very early stage; processing of the TL's lexical, syntactic and pragmatic features takes place more or less in parallel with SL comprehension (Macizo and Bajo 2004: 184):

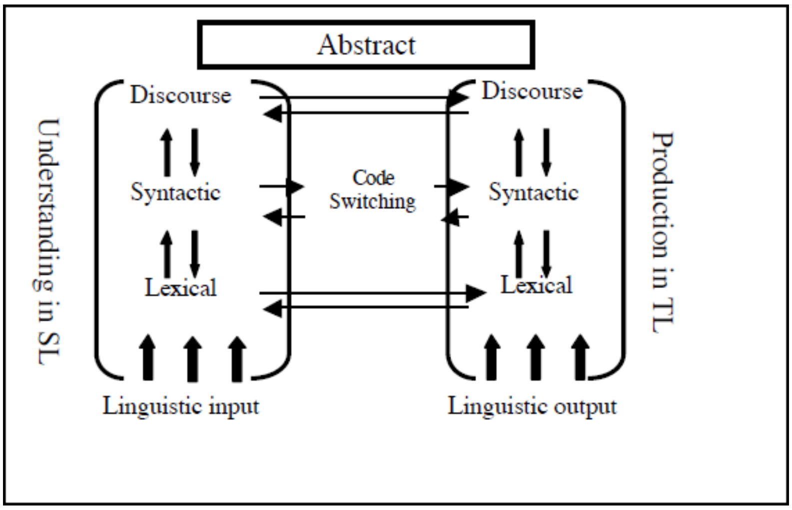

Figure 3c: Parallel processing during translation (from Macizo and Bajo 2004)

Several empirical studies have supported the parallel view of the translation process experimentally. One such study investigated the effect of L1 syntax on L2 processing in translation from Danish into English (Jensen *et al*. 2009 and Balling *et al.* 2009). The aim was to investigate if syntactic reordering during translation involved increased cognitive processing. To test this, translators were asked to translate texts in which some of the phrases required reordering of sentence constituents. In Danish, when a clause is introduced by an adverbial or some other fronted constituent, the finite verb always appears before the subject (V-S order). In English, the subject always appears before the finite verb (S-V order). It was therefore predicted that translation of the Danish V-S order clauses into English would require more cognitive effort. The results showed that significantly more cognitive effort, as indicated by increased gaze time during ST comprehension, was registered for sentences in which reordering is necessary. The results were taken as evidence of parallel processing at the syntactic level of translation, as translators were allocating cognitive resources to the syntactic reordering of TT constituents during comprehension, and not, as Seleskovitch's deverbalisation theory proposes, after comprehension is finalised. A 2008 study by Ruiz *et al.* (490-499) also suggested that rearrangement of syntactic structures was anticipated during SL comprehension. In addition, their study also found that pretranslation at the lexical level occurs during SL comprehension. Translators were instructed to engage in self-paced reading of sentences; the task involved reading for two purposes: L1 reading for repetition and L1 reading for L2 translation. The results showed that reading times of lexical items were significantly longer under the reading for translation task than under the reading for repetition task. Although Ruiz *et al.*'s findings lack one central feature of translation, i.e. language production (either spoken or written), the findings were taken to suggest that lexical processing during translation involves activation of the TL in parallel with ST comprehension. Ruiz *et al.*'s findings lend support to an interpretation of the findings of Jakobsen and Jensen (2008: 103), reported in section 3.3.1.1 below, who found that reading for translation in general is more time consuming than any other reading task.

The question remains whether ST processing and TT processing, from a WM perspective, can occur simultaneously so that both comprehension and reformulation occupy WM resources in parallel. The answer to this question is both yes and no. Yes, when considering the *storage* aspect of WM, as the phonological loop temporarily stores verbal ST information while the visuospatial sketchpad at the same time temporarily stores information about the planning of the TT message (see section 3.1.2); and no, when considering the *processing* aspect of WM, as the central executive can only maintain one controlled process at a time (see section 3.1.4). Considering that the *processing* aspect is a precondition for parallel *processing*, parallel ST/TT processing is not possible from a WM perspective since the translator cannot consciously engage in both ST comprehension and TT reformulation at the same time. It would, however, be possible that the allocation of processing resources alternates very rapidly between ST comprehension and TT reformulation. This type of parallel ST/TT processing, which strictly speaking is not parallel, would incur some cognitive cost on the part of the translator (see section 3.1.4.3).

There is also the question of whether ST processing and TT processing can occur in parallel when considering not only WM but also SM and the motor functions involved in typing. More specifically, it may be that while WM resources are completely engaged in ST comprehension, SM is at the same time briefly engaged in orthographic analysis during TT reading. It could also be that while WM resources are completely engaged in TT reformulation, SM is at the same time briefly engaged in orthographic analysis during ST reading. Both of these proposals entail that parallel ST/TT processing can occur only for as long as a visual impression has not reached WM (which is typically after 60 ms (see section 3.1.1)) Finally, it could be that while WM resources are completely engaged in ST comprehension, the translator is automatically executing typing events (see sections 3.2.2.3 and 3.2.3).

3.3 Tapping the translation process

The different methods of data extraction outlined in section 2.2 allow the researcher to probe the cognitive processes that underlie cognitive processing during translation. In the present study, eye tracking and key logging are used as the methodological framework for probing cognitive processes in translation. These two methods in combination offer a high degree of 'completeness' with respect to investigating the allocation of cognitive resources.

3.3.1 Eye tracking

Eye-tracking data are recorded with a device known as an eye tracker, which is capable of tracking and recording eye movements. Most systems register the participant's fixations, and some systems are also capable of recording saccadic eye movements and pupillary movement. Several types of eye trackers are available on the market. Types of systems used to study cognitive information processing include remote eye trackers (e.g. SMI's RED/RED250, SR Research's EyeLink 1000 Remote, Tobii's 1750, T60/T120 and TX300), head-mounted eye trackers (e.g. SMI's iView X HED, SR Research's EyeLink II, Tobii's Glasses Eye Tracker), and eye trackers which require that the head is kept stable (e.g. SMI's iView X Hi-speed and SR Research's EyeLink 1000 Head Supported). Remote eye trackers have the advantage that they are relatively non-intrusive compared to the other two types of eye trackers. The participant is free to move her head as the system compensates for head movement. The eye tracker's camera is usually hidden in the device, which makes it resemble a normal computer monitor. The main disadvantages of these eye trackers are that they are stationary (and thus not easily movable) and that they only record eye movements when the participant is looking at the screen area of the monitor. Head-mounted eye trackers have the main advantage that they record all eye movements, irrespective of the direction of the participant's head. The participant is also free to move her head, but the system is generally considered quite intrusive as it is fixed to the participant's head covering her eyes. Eye trackers which require that the participant's head is stabilised (for instance using a chin-rest or a bite-bar) have the overall advantage of reflecting far more accurately the location of the eye's fixations. However, they are also quite intrusive as they require that the participant keeps her head perfectly still. The last two types of eye trackers are often considered unfit for naturalistically oriented experiments as they may affect the participant's state of mind. With respect to translation experiments, these systems also have the added disadvantage of potentially complicating typing in the sense that visual contact with the keyboard may be partially or completely obstructed. Remote eye trackers are generally considered the better alternative of the three types of trackers. In this study, Tobii's 1750 remote eye tracker is used to collect data from the participants' eye movements (see section 5.1).

3.3.1.1 Fixations

Fixation, or more precisely visual fixation, is the continued maintenance of the visual gaze at a specific location so that the retina is stabilised over an object of interest (Duchowski 2007: 46). Although the term fixation suggests that the eye is physically stable and no movement occurs, some eye movement does in fact occur. During visual fixation, the eye is never perfectly still: micro-saccades, which are rapid, involuntary eye movements, ensure that the retina's light sensitive cells constantly receive updated visual impressions of an object of interest. If an impression were artificially stabilised on the retina, vision would rapidly fade (within a second) and no signal would be transmitted to sensory memory (e.g. Coppola and Purves 1996: 8001 and Duchowski 2007: 25).

Experiments have shown that fixation duration varies depending on the task (Rayner 1998: 373). More specifically, in non-reading tasks, such as scene perception, fixations are around 330 ms in duration. In reading, fixations are generally shorter: in silent reading, fixation duration is approximately 225 ms whilst in oral reading (reading aloud), fixation duration is approximately 275 ms. In reading while typing (i.e. reading of emerging text output during monolingual text production), fixation duration is substantially longer at approximately 400 ms. Rayner (ibid. 396), citing research by colleagues (Butsch 1932, Inhoff 1991), suggests that the reason for the longer fixation durations during typing is that the eyes wait in place for the hand to catch up.

A relative increase in fixation duration is generally considered indicative of an increase in cognitive load on the human memory system (cf. e.g. Just and Carpenter 1980, Rayner 1998: 398). An increase in fixation count has also been used as a measure of changes in cognitive load (Rayner 1998: 393). In translation process experiments, differences have been identified in fixation duration and fixation count under different conditions (e.g. Sharmin *et al.* 2008, Jakobsen and Jensen 2008, Pavlović and Jensen 2009). For instance, in a comparative study by Jakobsen and Jensen (2008: 112, also reported in Chapter 2), which investigated differences in reading behaviour according to reading task, it was found that mean fixation duration in ST reading during 'normal' comprehension was 205 ms. This mean fixation duration is somewhat similar to the fixation duration in silent reading, reported by Rayner. However, Jakobsen and Jensen's study found that the mean fixation duration for reading for translation was 218 ms (ibid.), which is more or less comparable to Rayner's observations. The small difference in fixation duration between reading tasks comes as a surprise; more specifically, longer fixation durations would intuitively be expected during ST reading and thus ST comprehension for translation (indicating more effortful processing), for instance, since many more of the propositions constructed during comprehension are retained (see section 3.2.1.2 above). One possible explanation for the similar fixation durations could be that ST reading for translation is not different from normal reading for comprehension with respect to cognitive load. However, the fixation count parameter in Jakobsen and Jensen's study showed that considerably more fixations were registered in the reading while typing a translation task (n = 1590) than in the reading for comprehension task (n = 145) (ibid. 109-111). Relatively more demanding lexical and propositional analyses could account for the ten-fold increase in fixation count. These observations provide a strong indication that considerably more cognitive resources are allocated to a translation task than to a 'normal' comprehension task.

The present study does not make observations on differences in fixation duration or fixation count to examine translators' allocation of cognitive resources. Rather, the notion of visual fixation is used as a theoretical basis for defining the study's so-called attention units (AU) (see section 3.3.3), which will be used to examine research question R2.

3.3.1.2 Saccades

Saccades are rapid eye movements that help reposition the centre of the retina, so that the retina may be stimulated by visual information from a new location (Duchowski 2007: 42). Saccades (or rather macro-saccades, to distinguish them from micro-saccades) occur between fixations, and they are characterised by large changes in eye position in an extremely short time span (up to 500° per second) (Rayner 1998: 373). During reading, saccades normally cover 2°, which corresponds to about 8 letter characters, and they normally last around 30 ms (e.g. Rayner and Pollatsek 1989: 113). Comparing typical saccade duration with fixation duration, saccades account for about 5-15 percent of all eye movements in reading, while the remainder 85-95 percent are fixations.

Computation of gaze duration has traditionally taken account of fixation durations only, and not saccade durations (Rayner 1998: 378). The main argument for excluding saccade duration has been that visual attention is disengaged from the object which was most recently fixated as no input is relayed from the retina to WM (e.g. Wright and Ward 2008: 133). However, cognitive processing of the recently fixated object has been found to continue during saccadic eye movements (cf. e.g. Rayner 1998: 378). Since the present study is interested in the *cognitive* processing that occurs during translation, and not eye movements as indicators of *visual* attention, saccadic eye movements are included as indicators of cognitive processing in the present study's analyses.

3.3.1.3 Eye-mind and immediacy assumptions

Just and Carpenter (1980: 331) formulated the influential 'eye-mind' and 'immediacy'-assumptions. With respect to the eye-mind assumption, Just and Carpenter propose that "there is no appreciable lag between what is being fixated and what is being processed", and for their immediacy assumption they state that "... the interpretations at all levels of processing are not deferred; they occur as soon as possible" (ibid.). In reading, it follows from these two assumptions that at the moment a word enters into the eye's focus, cognitive resources are allocated to its processing. Processing of the word continues without interruption until the word is no longer within the eye's focus. For example, if the eye tracker registers a fixation (or consecutive fixations) on the word *car* in a given text which lasts 414 ms, then it is assumed that, during the entire duration of the fixation(s), the meaning of the word is being processed. Other researchers have also pointed out a strong connection between the location of a fixation and cognitive processing (e.g. Posner 1980, Anderson 2000). Anderson states that: "we are attending to that part of the visual field which we are fixating" (2000: 81). In line with the eye-mind assumption, Anderson assumes that the object which is at the centre of visual focus is also at the centre of cognitive focus. Although he does not put forward a claim similar to Just and Carpenter's immediacy assumption, it might be assumed that Anderson also takes it that eye fixation and cognitive processing co-occur without delay.

The eye-mind assumption (and indirectly also the immediacy assumption) has been a target of criticism since it was first formulated. For instance, Posner (1980: 5-6) describes a relevant distinction between two types of attention during reading: overt attention and covert attention; overt attention is the action of voluntarily bringing into visual focus an object of interest to which cognitive resources are allocated; covert attention is the action of allocating cognitive resources to an object extrafoveally, which means that the reader is allocating cognitive resources to the processing of an object which is *not* in visual focus. Although, intuitively, there is a relationship between the location of a fixation and cognitive processing, it cannot be excluded that a person is focussing attention on an object covertly. In other words, since the focus of cognitive processing can shift independently of eye movement, it cannot be assumed, with absolute certainty, that a person is cognitively processing the object at which she is fixating.

Another concern about Just and Carpenter's assumptions relates to saccadic eye movements. During saccadic eye movements, which account for around 5-15 percent of all eye movements in reading (see section 3.3.1.2 above), visual attention is known to be suppressed or even disengaged (Wright and Ward 2008: 133). This means that the eye is in fact momentarily blinded in the sense that no visual input is registered by the retina. Therefore, no new visual input is relayed through the visual cortex to the memory system. This disengagement of visual attention is said not to interfere with cognitive processing, which is sustained during the saccadic eye movement (Rayner 1998: 378). It may accordingly be assumed that the type of cognitive processing that takes place during a saccade is similar to that which took place in the most recent fixation. This assumption is supported by research indicating that sensory memory retains an impression of visual information for around 500 ms (see section 3.1.1 above). So, although relay of visual information from the retina to the memory system is suspended during a saccade, an impression from the most recent fixation is kept in sensory memory during the course of the saccadic movement, and the information is therefore still available for cognitive processing.

With respect to the case of translation, it cannot be excluded that the translator is engaging in TT reformulation although eye movement is registered in the ST area of the screen, and it cannot be excluded that the translator is engaging in ST comprehension although eye movement is registered in the TT area of the screen. Similarly, it cannot be maintained with absolute certainty that the translator is engaging in parallel ST/TT processing although the eye tracker has registered eye movement in the ST area of the screen which coincides in time with typing. Nevertheless, it is assumed that the vast *majority* of the eye-tracking data reflects cognitive processing of the content at which the translator's gaze is directed. More specifically, when the translator looks at the ST area of the screen, she will, for the most part, be engaged in ST processing; and when she looks at the TT area of the screen, she will, for the most part, be engaged in TT processing. It is not possible to experimentally take into account the extent to which covert attention and saccadic eye movements could affect a study's findings. It is, however, assumed here that the possible detrimental effects of these potentially error-inducing factors of covert attention and saccadic eye movements on the results are distributed evenly across all translations and all participants. In other words, the volume of covert attention and saccadic eye movements in translation does not vary between the study's participants or between the participants' translations.

3.3.1.4 Pupillary movement

The pupil is a small opening in the centre of the eye's iris that allows light to enter the eye's retina. The size of the pupil, which can vary from 1 mm to 9 mm in diameter, is controlled by two types of muscles: the sphincter pupillae, which decreases the size of the pupil, and the dilator pupillae, which increases the size of the pupil. These two types of muscles, and thereby pupillary constriction and dilation (*pupillary movement*), are innervated by the autonomic nervous system (Beatty and Lucero-Wagoner 2000: 145). Pupillary movement may be induced by reflexive stimulation, such as the pupillary light reflex, by influx of adrenaline or by cognitive events (ibid. 144). Quoting Kahneman (1973), Beatty and Lucero-Wagoner (2000: 144) note that "of special interest (...) are those changes in pupil diameter that are the systematic indicators of attention and mental effort." Below, this type of pupillary movement will be examined as an indicator of cognitive load.

Measurement of changes in pupil size is recognised as a reliable indicator of the processing intensity of the cognitive resources allocated to a given task (i.e. cognitive load) (e.g. Hess and Polt 1964, Kahneman 1973, Beatty 1982, Beatty and Lucero-Wagoner 2000). Hess and Polt (1964) were the first to suggest that pupillary responses could be used as an indicator of cognitive load. In an experiment (ibid.; reported in Beatty and Lucero-Wagoner (2000)), five participants were asked to solve multiplication tasks. Hess and Polt observed that pupillary responses were closely correlated with mental activity as the size of the pupil increased with the difficulty of the multiplication task. Subsequent experiments have supported Hess and Polt's findings of a correlation between pupillary response, cognitive load and task complexity (e.g. Ahern and Beatty 1979, Iqbal *et al*. 2005).

Within the field of translation process research, pupillometric measurements have been used to investigate processing loads during interpreting (Hyönä *et al.* 1995) and recently also to study cognitive effort in translation (e.g. O'Brien 2006a, Pavlović and Jensen 2009). O'Brien (2006a) compared pupil size measurements with translation memory matches and found a correlation between cognitive load and match type. More specifically, O'Brien observed that translation of segments for which there were no translation memory matches was associated with the heaviest cognitive load, while translation of segments for which there were 100 percent memory matches was associated with the least cognitive load. Pavlović and Jensen (2009) (see also sections 2.2.1 and 2.2.2) used pupillometric data to study cognitive load in relation to translation directionality. They found that pupils were more dilated during TT reformulation than during ST comprehension, which was interpreted as more cognitive effort being allocated to TT reformulation than to ST comprehension. In the present study, measurements of pupil size are used to examine research question R3, which focuses on the relationship between variation in cognitive load and the allocation of cognitive resources.

Experiments have shown that pupillary response to a stimulus occurs with some delay (also referred to as pupillary latency or pupillary reaction time) (e.g. Beatty 1982, Kramer 1991, Hyönä *et al.* 1995). Pupillary dilation or constriction in response to changes in cognitive load is delayed relative to the participant's increased or decreased allocation of cognitive resources to a task. Beatty (1982) estimates that pupillary delay is between 100 ms and 200 ms. Hyönä *et al.* (1995: 605) estimate the delay at 300-500 ms, while Kramer (1991) estimates the delay at 600 ms. Since pupillary response and the allocation of cognitive resources are not synchronous, the immediacy assumption does not extend to pupillary response as reflections of cognitive effort. It is therefore considered relevant to take into consideration pupillary latency when analysing pupillometric data. The present study assumes a rather short pupillary latency of 120 ms (see section 5.2.3.2).

Pupillary movement is sensitive to factors other than cognitive events. Pupillary movement may be induced by changes in luminance, by stress, disease, the use of medicine, drugs and alcohol etc. (e.g. Krüger 2000, Verney *et al.* 2001, Kaeser and Kawasaki 2010). Some of these potentially error-inducing factors can be controlled for experimentally while others are not as easily controlled. In the present study, changes in pupil size, which could be related to differences in light intensity, were controlled for by using the same light source during the experiments (see also Chapter 5).

In conclusion, Just and Carpenter's eye-mind assumption proposes a correlation between cognitive processing and the object at which a person is gazing. The amount of time in which the eyes fixate an object corresponds to the amount of time in which the translator is processing that very object. In line with Just and Carpenter's assumptions and the discussion above, it is assumed here that pupillary movement is a reliable indicator of cognitive load in translation, taking into account that the pupil's reaction to changes in cognitive load is asynchronous relative to a cognitive event. Larger pupil sizes are assumed to reflect heavier cognitive load and smaller pupil sizes are assumed to reflect lower cognitive load.

3.3.2 Key logging

Key-logging data have been used to make inferences about cognitive processing during translation (see also section 2.2). The present study assumes that typing events are evidence of cognitive resources being allocated to TT processing.

A distinction was emphasised in section 3.2.2.3 between the levels of processing involved in typing. Typing consists of cognitively demanding motor instruction followed by low cognitively demanding typing executing. This means that the moment at which a typing event is registered by a key logging program is likely not to coincide in time with the moment at which the typing event is cognitively initiated. Research within the field of neuroscience has demonstrated that different areas of the brain are activated at different points throughout a typing process (Benarroch 2006: 496). More specifically, a study investigating brain activation in self-initiated finger movement using PET and MEG[12] (ibid.) identified motor cortex activation 300 ms before finger movement and up to 100 ms after finger movement. In addition, activation in the middle frontal gyrus, which is often associated with WM (cf. e.g. Frazier *et al*. 2005, 555), was observed 900 to 250 ms before finger movement. These findings suggest that WM processes are involved in performing a typing event until 250 ms before the keyboard key is actually pressed. The present study takes into account the difference in onset of a typing event and actual typing event by considering a preceding time span of 200 ms[13] evidence of typing. By doing so, it is assumed that a typing event is indicative of WM resources being allocated to TT processing, at least, at the very beginning of the 200 ms time span. In the present study, two typing events that are no farther apart than 200 ms will thus be considered part of the same string of typing events (see section 5.2.2).

Touch typing skills, naturally play a role in a translator's capacity to type a TT without looking at the keyboard. Touch typists will look more at the screen while typing, whilst non-touch typists will look less at the screen while typing. Although no studies have compared professional translators' and student translators' ability to touch type, it may tentatively be argued that professional translators are better at touch typing than student translators since they are most often more experienced typists. It is therefore anticipated that professional translators engage in more parallel ST/TT processing, as indicated by eye movement data and key-logging data, than do student translators (see also section 3.3.3, below).

[12] PET (positron emission tomography) and MEG (magnetoencephalography) are neuro-imaging techniques that are used to map brain activity.
[13] Based on Benarroch's (2006) 250 ms minimum time span from WM activation to finger movement, a conservative time span of 200 ms was chosen to account for measurement error.

3.3.3 Attention units

The term ‘attention unit’ has been used in cognitive psychology and translation process studies in related but slightly different ways from its usage in this study. Newell and Simon (1972: 313) investigated human problem-solving activities using a combination of eye-tracking data and TAP. With respect to eye tracking, they used the term attention unit to describe “a series of [visual] fixations devoted predominantly to a single task-relevant locale in the display”, and an attention unit is to be interpreted as concurrent problem-solving activity engaged in by the participant (ibid.); it follows from Newell and Simon’s definition that all (aggregate) gaze activity allocated to a specific area is indicative of cognitive processing of the content of that area. This assumption is in line with Just and Carpenter’s later eye-mind assumption. Jääskeläinen (1999: 161) adopts Newell and Simon’s terminology, but she uses it somewhat differently. While the attention unit is still considered a unit of problem-solving activity, or an instance of *marked* processing which interrupts the smooth unproblematic flow of the translation process (1999: 161-162), Jääskeläinen does not identify attention units on the basis of observations of fixations. Instead, she identifies instances of problem-solving activity on the basis of TAP data. Jääskeläinen acknowledges that the boundaries of her attention units are not as clearly identifiable as Newell and Simon’s (ibid.).

In the present study, the attention units (AUs) are comparable to those of Newell and Simon, which have clearly identifiable boundaries and mark instances of cognitive processing (or *problem-solving*). An AU is taken as a time measurement unit of uninterrupted cognitive processing, as indicated by eye movement data (fixations and saccades) and typing events. Relying on the eye-mind and immediacy assumptions, a visual shift from one type of activity to another indicates a shift in the allocation of cognitive resources from one object to another object (see also Bock *et al*. 2008: 946). For instance, a shift in visual attention during a translation task from a word in the ST to a word in the TT indicates that the translator is no longer allocating cognitive resources to the processing of the ST word but that she is instead allocating resources to the processing of the TT word.

More specifically, the type and duration of an AU are determined by three properties: (1) the task to which the participant is focussing attention (i.e. ST processing, TT processing or parallel ST/TT processing) defines the *type* of the AU, (2) the *latest* attention shift away from the most recent AU defines the *beginning* of the AU, and (3) the *next* attention shift away from the AU defines the *end* of the AU. Figures 3d and 3e illustrate how AUs are composed of eye movements and typing events. The first figure below is an example, which illustrates the three indicators of attention (fixations, saccades and typing events) prior to categorising them according to AU. The numbers illustrate the chronological order in which fixations and typing events occur:

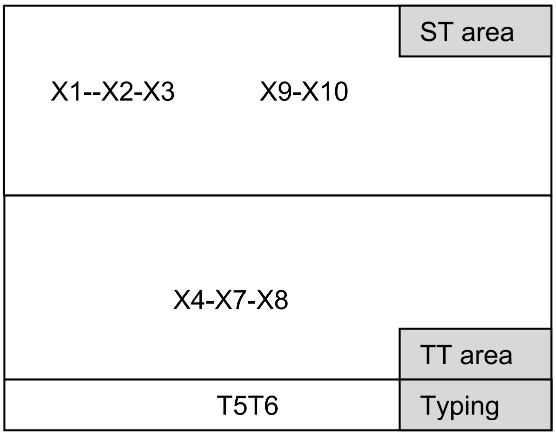

Figure 3d: Indicators of attention before AU categorisation ('X' = *fixation*, '-' = *saccadic eye movements*, and 'T' = *typing events*).

The location of the indicators of attention on the screen, as represented in Figure 3d, could seem arbitrary, at least if the chronological order of fixations and typing events is ignored. However, if fixations, saccades and typing events are categorised according to chronology and according to the type of cognitive processing they reflect, three AUs appear, as illustrated in Figure 3e below:

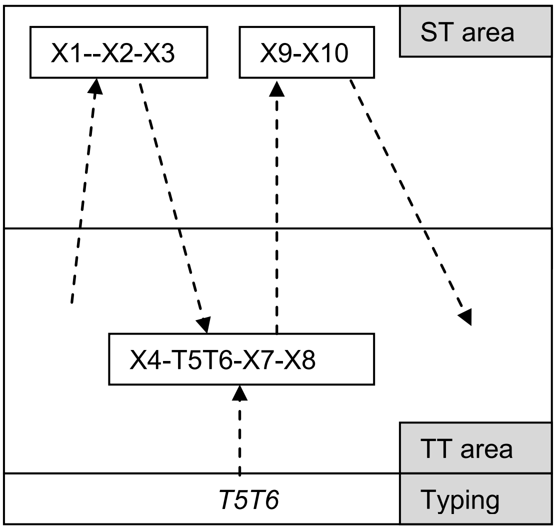

Figure 3e: Indicators of attention after AU categorisation ('X' = fixation; '-' = saccade; 'T' = typing event).

Figure 3e shows that the three indicators of attention make up two AUs in the ST area of the screen (STAUs) and one AU in the TT area of the screen (TTAU). The two STAUs and the one TTAU consist of uninterrupted chains of fixations and saccades (and also typing events in the TTAU). These chains are discontinued by attention shifts between ST processing and TT processing. In addition to STAUs and TTAUs, there is also the possibility of parallel attention units (PAUs), which occur when fixations or saccades, registered in the ST area of the screen, co-occur with typing events.

With respect to the subprocesses (see sections 3.2.1 and 3.2.2) involved in each type of AU, Table 3d below lists those considered to be involved in an STAU, TTAU and PAU.

Table 3d: Attention units and types of subprocesses

Attention Unit (AU)	***Types of subprocesses***
ST attention unit (STAU)	ST reading and ST comprehension
TT attention unit (TTAU)	TT reformulation and either TT reading or TT typing
Parallel attention unit (PAU)	ST reading and ST comprehension *AND* TT reformulation and TT typing

Ideally, one STAU involves all the subprocesses involved in ST processing (ST reading and ST comprehension), constituting a ‘complete’ ST processing cycle. Similarly, a TTAU would, ideally, involve the subprocesses and levels of processing involved in TT processing (either TT reformulation (only planning and encoding) and TT typing, or TT reading TT and reformulation (only verification)), constituting one ‘complete’ TT processing cycle. Such ‘complete’ processing cycles most likely do not occur often. For instance, meaning construction might well stretch over several STAUs, and TT reformulation might also stretch over several TTAUs. Indeed, it would be hazardous to claim unconditionally that STAUs and TTAUs are reflections of such ‘complete’ processing cycles; such a claim would also contrast with the findings of Dragsted and Hansen’s (2008) study (see also section 2.2.1), which showed that the *eye-key* span, which is the time that elapses from the first reading of an ST word to the first typing event that is related to its translation, may be several seconds. In one case, they found that the eye-key span for one particular ‘problem’ word was between 39 and 102 seconds for a group of translators. It is likely that attention would shift a number of times between ST processing and TT processing during these long time spans. All other things aside, it is, however, a reasonable assumption to make that each STAU involves comprehension and that each TTAU involves reformulation as part of ‘partial’ processing cycles. With respect to PAUs, it is assumed that these involve the subprocesses of ST processing and TT processing as ‘partial’ parallel processing cycles. This matter of ‘complete’ and ‘partial’ processing cycles involved in an AU will not be debated any further in this study, but it is considered very likely that partial processing occurs during each AU as part of larger processing cycles.

An important methodological consideration should be mentioned with respect to PAUs and parallel processing. Parallel processing is probably not limited to those instances (i.e. co-occurring ST reading and TT typing) that are recorded with the equipment used in the present study (i.e. key logging and eye tracking). As documented in Ruiz *et al.*'s (2008) study, which was discussed in section 3.2.4.2, activation of TL processing can take place without any typing event taking place. It is therefore likely that parallel processing can occur without being registered in the data. The observations made with respect to parallel ST/TT processing in the present study are obviously restricted to those instances in which ST reading and TT typing co-occur. A distinction is therefore made between *manifested* parallel processing and *non-manifested* parallel processing.

3.4 Assumptions and hypotheses

Key assumptions, which are based on the discussions of this chapter, are presented below. They will undergo no further testing or elaboration but will serve as a basis for identifying the study's indicators of cognitive resource allocation and as a basis for formulating and evaluating the study's hypotheses.

3.4.1 General assumptions

The memory system

Sensory memory is a transient memory which forwards pre-processed incoming visual impressions to working memory after around 60 ms (Jaekl and Harris 2007). In addition, information is held in sensory memory for around 500 ms (Eysenck and Keane 2010) (section 3.1.1).

Working memory integrates, processes and manipulates sensory and long-term memory information (Baddeley 2000), and its capacity is limited (Miller 1956, Peterson and Peterson 1959). Working memory is considered central to the translator's allocation of cognitive resources in translation (section 3.1.2).

Long-term memory stores information permanently. Long-term memory is divided into procedural memory, which is the knowledge of *how* to perform motor and cognitive actions, and declarative memory, which is the conscious recollection of facts and events (James 1890, Eysenck and Keane 2010). Both types of long-term memory are involved in the translation process (section 3.1.3).

The central executive of working memory is responsible for focussing, dividing and switching attention (Baddeley 2007). The allocation of cognitive resources during translation is therefore determined by the central executive (section 3.1.4).

The processes of translation

Cognitive processing during translation consists of, at least, ST processing, TT processing and parallel ST/TT processing.

ST processing consists of ST reading, which mainly involves sensory memory, and ST comprehension, which mostly involves working memory (section 3.2.1).

TT processing consists of TT reading, TT reformulation and TT typing. TT reading involves mainly sensory memory, TT reformulation draws mainly on working memory and TT typing relies to some extent also on working memory (section 3.2.2).

Indicators of cognitive processing

The location of the eye's fixation corresponds to the information being processed by the human memory system without appreciable delay (Just and Carpenter 1980) (section 3.3.1.3). Eye movement data registered in the ST area of the screen reflect ST processing and eye movement data registered in the TT area of the screen reflect TT processing (section 3.3.3).

Key-logging data are indicative of TT processing by the human memory system (Jakobsen 1998). Typing events are cognitively initiated around 200 ms prior to their execution (3.3.2).

Pupil size data are indicative of the cognitive load placed on working memory (Hess and Polt 1964, Kahneman 1973), as larger pupils, measured with a 120 ms delay, reflect higher cognitive load, and smaller pupils, measured with a 120 ms delay, reflect lower cognitive load (section 3.3.1.4).

Parallel ST/TT processing by the human memory system (Gerver 1976, de Groot 1997) is indicated by the simultaneously registered key-logging data and eye-movement data in the ST area of the screen (section 3.3.3).

In order to make inferences about the translators' allocation of cognitive resources during translation, three indicators are defined. These proposed indicators will constitute the study's three dependent variables:

TA duration – Distribution of cognitive resources

Total attention (TA) duration is defined as an indicator of the distribution of cognitive resources as indicated by the total amount of time spent on a given translation under a given condition.

AU duration – Management of cognitive resources

Attention unit (AU) duration is defined as an indicator of the translator's management of cognitive resources during translation (or *capacity management* cf. Gile 1995), as it reflects the translator's focussing of attention on and division and switching of attention between cognitive processes. In other words, AU duration is taken to reflect the translator's *conscious* response to the processing requirements of the translation task.

Pupil size – cognitive load

Pupil size is defined as an indicator of the cognitive load that is placed on working memory (Hess and Polt 1964, Kahneman 1973) during translation by one or several cognitive processes that occupy working memory's limited pool of cognitive resources (Baddeley 2007).

3.4.2 Hypotheses

The hypotheses presented below are motivated in part by the empirical findings presented in section 2.2 and in part by the discussion of the memory system and the subprocesses of translation throughout Chapter 3. As the present study is exploratory in nature, the hypotheses are kept fairly simple, and they relate just one dependent variable (TA duration, AU duration or pupil size) to one independent variable (processing type, translational expertise, source text difficulty or time pressure). These simple hypotheses will constitute points of departures for further analysis and discussion as *interactions* between one dependent variable and *multiple* independent variables will be considered.[14]

ST processing and TT processing and the allocation of cognitive resources

The allocation of cognitive resources in translation is co-determined by the processing requirements of ST processing and TT processing, which impose different demands on the human memory system (sections 2.2.1, 3.1.4 and 3.2).

H1a: Translators spend more time on TT processing than on ST processing.

H5a: TTAUs are of longer duration than STAUs.

H9a: Cognitive load is higher during TT processing than during ST processing.

Parallel ST processing and TT processing and the allocation of cognitive resources

The allocation of cognitive resources in translation is co-determined by the limitations of the human memory system to engage simultaneously in both ST processing and TT processing (section 3.2.4.2).

H1b: Translators spend less time on parallel ST/TT processing than on ST processing and TT processing.

H5b: PAUs are of shorter duration than STAUs and TTAUs.

H9b: Cognitive load is higher during parallel ST/TT processing than during ST processing and TT processing.

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[14] The groups of hypotheses are presented here according to independent variable. The hypothesis designations (H1, H2 ... H12) indicate the order in which they are dealt with in the analyses in Chapter 6.

Expertise and the allocation of cognitive resources

The allocation of cognitive resources in translation is co-determined by expertise as experienced translators and less experienced translators process translation differently (sections 2.2.2 and 3.1.4).

H2: Student translators spend more time on a translation task than professional translators.

H6: AUs are of longer duration for student translators than for professional translators.

H10: Cognitive load is higher for student translators than for professional translators.

Source text difficulty and the allocation of cognitive resources

The allocation of cognitive resources in translation is co-determined by the level of difficulty of the source text as different demands are placed on the translator's memory system (sections 2.2.3 and 3.1.4).

H3: The translation of a difficult source text requires more time than the translation of an easy source text.

H7: AUs are of longer duration for difficult source texts than for easy source texts.

H11: Cognitive load is higher when a difficult source text is translated than when an easy source text is translated.

Time pressure and the allocation of cognitive resources

The allocation of cognitive resources in translation is co-determined by the time condition under which the translation is carried out as different amounts of time are available to perform the same cognitive operations (sections 2.2.4 and 3.1.4).

H4: Translation under time pressure is performed more quickly than translation under no time pressure.[15]

[15] Hypothesis H4 may seem self-evident. However, as noted above, each hypothesis is formulated so that it relates just one dependent variable with one independent variable (in this case time

H8: AUs are of shorter duration under time pressure than under no time pressure.

H12: Cognitive load is higher when a text is translated under time pressure than when a text is translated under no time pressure.

The first research question **R1**, which asked “What is the distribution of cognitive resources during translation?”, will be examined by testing hypotheses **H1a**, **H1b**, **H2**, **H3** and **H4**. TA duration is used as the dependent variable. (Section 6.1).

The second research question **R2**, which asked “How are cognitive resources managed during translation?”, will be examined by testing hypotheses **H5a**, **H5b**, **H6**, **H7** and **H8**. AU duration is used as the dependent variable. (Section 6.2).

The third research question **R3**, which asked “How does cognitive load vary during translation?”, will be examined by testing hypotheses **H9a**, **H9b**, **H10**, **H11** and **H12**. Pupil size is used as the dependent variable. (Section 6.3).

pressure). Potential interaction effects with the other factors (processing type, translator expertise and source text difficulty) will be considered when investigating the validity of the hypothesis.

Chapter 4
Research design

A series of translation experiments were carried out in which 24 translators had their eye movements and typing activities registered with an eye tracker and with key logging software. The experiments were carried out at the Copenhagen Business School from April 2008 to May 2009. It was deemed most appropriate to carry out all the translation experiments at the same location for several reasons. First of all, moving the eye tracker, which weighs around 15 kilograms, to the location of the translator was not considered a realistic option. More importantly, however, the setting in which the participants were to carry out the translation experiments had to be the same for all in order to avoid effects that had to do with potential differences in light intensity, distance to the monitor, etc. (see section 5.1.2).

Target text quality

The present study's focus is on the allocation of cognitive resources in translation, and it is therefore considered to be outside the scope of this study to assess the quality of the participants' translations. Since the cognitive processes that constitute the translation process are central to the present study, assessment of TT quality would not have provided relevant information about the *allocation* of cognitive resources in translation; that being said, it would have been interesting to explore potential *correlations* between the process data and the quality of the participants' translations: for instance, it would have been interesting to examine if there were a relationship between the allocation of cognitive resources and TT quality; it would also have been interesting to examine if there is a relationship between TT quality and the duration of AUs and pupil size. However, these questions would most likely constitute research projects by themselves.

Ecological validity

One drawback of carrying out the translation experiments at the same location is that the participant's state of mind may be affected because she is not translating in her usual work environment. Thus, there is a risk that translation process data collected in an 'artificial' environment are not comparable to process data collected in a more familiar environment. In addition, it might also be argued that the use of an eye tracker to collect data affects the participants' state of mind negatively, which could increase the risk of a 'white coat effect'. It is nevertheless expected that these issues will not affect the translators' allocation of cognitive resources, in part because the translators were given a warm-up text, prior to the real experiments in order to acclimatise them to the translation situation (see section 4.2).

Another factor which might contribute negatively to the validity of the data is that the translation task is also 'artificial' in the sense that the translations, and thus the translation process data, only served as material for the analyses of the present study. In other words, the participants were aware that their translations would not be applied in a real-life setting. As pointed out by Dragsted (2004: 126), this potential problem is probably less of an issue with student translators, who are used to translating for the purpose of having the translation evaluated by a teacher. With respect to professional translators, they might feel less responsible for producing a translation that meets their usual quality criteria. It is expected, however, that this problem will affect the orientation and revision stages more than it will affect the drafting stage (see section 3.2), and since the present study concerns the part of the translation process in which translation is drafted, this issue is considered to have minimal effect.

4.1 Participants

In the investigation of differences in allocation of cognitive resources in relation to translational expertise, this study adopts a distinction between two groups of translators which is based on two parameters: the first is one of translation experience and the other is one of level of education. It is anticipated that translation experience and level of education relevant to translation studies are useful to distinguish professional translators from non-professional translators. The professional translator group consisted of 12 professional translators (nine women) who held degrees in translation studies and were certified translators. All professional translators had at least three years of experience working as translators translating between Danish (L1) and English (L2) (see also Appendix A1). The student translator group (the non-professional translators) consisted of 12 MA students (11 women), who all specialised in translating between Danish (L1) and English (L2). The student translators generally had little or no professional translation experience (see also Appendix A2). Although it cannot be said that the two groups were internally homogenous with respect to translation experience, they did nevertheless differ in the sense that all the professional translators had more professional translation experience than the student translators.

The participants were each assigned a letter and a number: professional translators were assigned the letter 'P' and a number (1-12) and student translators were assigned the letter 'S' and a number (1-12). Translations from three additional participants (one male professional translator, one female professional translator and one female student translator) were discarded due to poor eye-tracking data quality (see section

5.1.2). Participants whose data were discarded were assigned the letter 'D' and a number (1-3). The analyses of the present study were based on data from a fairly high number of (24) participants. It is assumed that the higher number of participants in a study, the more likely is it that the findings can be interpreted as correlates of real-world circumstances.

As noted above, the study analysed data from 20 women translators and 4 male translators. No attempt was made at recruiting an equal number of men and women. Recruitment of professional translators and student translators is a difficult task in itself due to the relatively small number of practitioners and student translators translating between L2 English and L1 Danish; in a profession which is dominated primarily by women, a recruitment requirement which stipulates an equal number of men and women would make recruitment even more problematic. Although the possibility exists that gender imbalance may affect the results, it was not anticipated that these differences would be decisive to the study's conclusions.

4.2 Task

The participants in the present study were each tasked with translating four texts: one warm-up text, which was presented as the first text, and three experimental texts (see section 4.3). The participants were informed that data from all four texts would be subjected to analysis, although the warm-up text in reality only served the purpose of acclimatising the participants to the translation situation. Having completed their translation of the warm-up text, each participant was tasked with translating the three experimental texts. Two of the three experimental texts were translated with a time constraint, while one was translated without (see section 4.4). The sequence (see section 4.5) in which the texts were presented was semi-randomized so that the study's experimental texts and the time constraint conditions were presented an equal number of times in different positions (in initial position, in medial position and in final position).

No online or offline translation aids were made available. It was assumed that accessibility to dictionaries, parallel texts etc. could lead to a reduction in the amount of recorded eye-tracking data. If *offline* translation aids had been available, the participants might have looked away from the screen which would have reduced the amount of analysable eye-tracking data. If *online* translation aids had been available, the eye-tracking data would partially have reflected gaze activity that did not directly reflect ST processing, TT processing or parallel ST/TT processing. This would have complicated the interpretability of the analyses of Chapter 6 considerably since eye-tracking data, which did not reflect ST processing, TT processing or parallel ST/TT processing, would have to be identified and discarded manually prior to analysis.

4.2.1 Translation brief

Prior to the execution of the experiments, the participants were told that a total of four experimental texts were to be translated. Two of those were to be translated under time constraints while two would be translated without time constraint. The participants were asked to produce translations that would satisfy their usual quality criteria, and they each received a gift certificate for their participation. These steps were intended to facilitate a state-of-mind in which the participants would experience the translation situation as more authentic and less clinical. The participants were not informed that the first text was a warm-up task, and that the data from this text would not be analysed. It was supposed that the participants would achieve the desired state-of-mind more quickly, in due time for the translation of the first of the three experimental texts.

4.3 Source texts

The three source texts (TextA, TextB, TextC) used in the study were based on articles on current news topics that appeared in British newspapers in 2008. TextA was from *The Independent* and was about a hospital nurse who had been poisoning elderly patients; TextB was from the *Daily Telegraph* and was about the increasing cost of living in the United Kingdom; TextC was from *The Times* and was about the crisis in Darfur and China's Africa policy (see Appendix B).

The original articles were manipulated with two aims in mind. Firstly, the experimental texts had to be comparable with respect to their total number of characters and the length of their headlines so that there was a uniform basis for comparison. Secondly, since one aim of the study was to make observations on translators' allocation of cognitive resources when translating texts of different levels of difficulty, the levels of complexity of the experimental texts were made to vary (see section 4.3.1).

The experimental texts were made rather short (TextA: 837 characters with spaces (ws), TextB: 846 characters ws, TextC: 856 characters ws). Texts longer than 900 characters (presented in 18-point Tahoma and double line spacing on a 17" LCD monitor at 1280 x 1024 pixels) would require that the participants had to scroll the ST window in order to read the sentences at the end of the text. Since the present study's analyses rely on a static image of the ST being displayed at the same locale of the screen throughout the translation session (see section 5.2), longer texts were deemed impractical.

4.3.1 Source text complexity

An aim of the study is to make observations on the effect of source text difficulty on the allocation of cognitive resources. It is assumed that the subjective notion of source text difficulty is indicated by a text's level of complexity; in other words, a complex text will be perceived as difficult and a less complex text will be perceived as less difficult. The levels of complexity of the experimental texts were established using three quantitative indicators, following Jensen (2009: 63): measurements of readability, calculations of word frequency and calculations of the number of occurrences of non-literal expressions, i.e. idioms, metaphors, and metonyms.

It is assumed that these objective measurements, to some extent, indicate the level of difficulty experienced by the participants when comprehending the experimental texts. Following Jensen's (ibid.) suggestions, it is here assumed that measurements of complexity in general-purpose texts, such as the experimental texts used in this study, are strong indicators of source text difficulty in translation.

A panel of three reviewers, who had British English as their mother tongue, were tasked with reading the three experimental texts. Upon finishing reading each text, the panellists filled out a questionnaire; in the questionnaire, the panellists rated the texts from 1 (low level) to 5 (high level) on their level of comprehensibility, level of coherence and level of grammatical correctness (See Appendix C). According to the questionnaire data, all three texts scored between 4 and 5 on average, and they were therefore considered acceptable for inclusion in the present study. After having read the texts and filled out the questionnaires, the panellists also rated the texts according to the level of difficulty. TextA was deemed the easiest text by all panellists and TextC was deemed the most difficult.

Readability measurement

Measurements of the experimental texts' levels of readability (i.e. comprehensibility) were made using seven different readability indexes (Jensen 2009: 64). Five of those provide indication of the U.S. grade level that the reader must have completed to fully comprehend the text: the Automated Readability Index (ARI), the Flesch-Kincaid index, the Coleman-Liau index, the Gunning Fog index, and the SMOG index. Two indexes, Flesch Reading Ease and LIX,[16] return numerical scores.

All seven indexes applied to test the levels of readability showed a progression in the level of complexity from TextA to TextB to TextC. The U.S. grade level indexes revealed that an average of 7.8 years of schooling was needed to successfully comprehend TextA; 12.5 years of schooling was needed to successfully comprehend TextB, while 17.3 years of schooling was needed to successfully comprehend TextC.

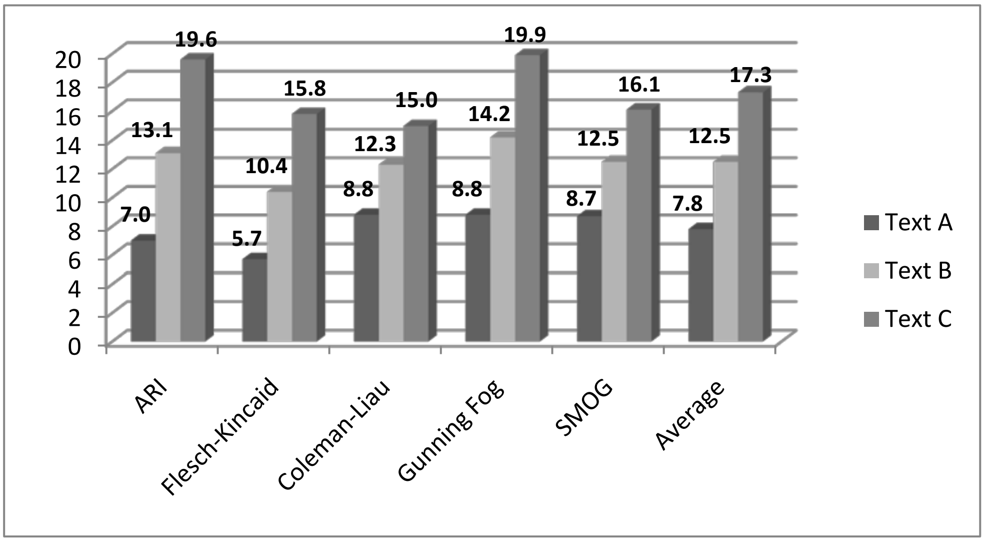

Figure 4a: Source text complexity scores of TextA, TextB and TextC arranged by U.S. grade level indexes scores (in years)[17]

The Flesch Reading Ease index returns numerical scores from 0 to 100. Higher scores indicate that a text is easy to understand while lower scores indicate that a text is difficult to understand. According to The Flesch Reading Ease index, the experimental texts received the following scores: TextA: 79.8, TextB: 59.4, and TextC: 37.7, making TextA the easiest text and TextC the most difficult. The LIX index[18] groups text according to five categories of difficulty: very easy texts (<25), easy texts (25-35), average texts (35-45), difficult texts (45-55), and very difficult texts (>55). On the LIX index, the texts received the following scores: TextA scored 31, TextB scored 45, and TextC scored 60, making them *easy*, *average* and *very difficult*, respectively.

[16] LIX (Swedish abbreviation for *läsbarhetsindex* (i.e. *readability index*)).
[17] *Editcentral* [www.editcentral.com] was used to calculate the index scores. *Editcentral* is a website that returns the complexity scores of a text which is entered into an online query box by the user. The website returns complexity scores for all readability indexes except for LIX.
[18] *Bedreword* [www.bedreword.dk] is a website from which add-in programs for Microsoft Word can be downloaded. The *BedreWord/Lixberegning* add-in program was used to calculate complexity scores based on the LIX formula.

Readability indexes are only sensitive to the surface structure of a text (Jensen 2009: 68). The indexes reported above base their scores on calculations of character length, sentence length and syllable length, and they fall short of making predictions about the perceived difficulty of single words or compounds. For instance, two words may be similar with respect to character count and syllable count, but the subjective level of *familiarity* may differ greatly from one reader to another. In the present study, the measurement of the texts' levels of readability was therefore complemented with other indicators.

Word frequency

Based on the common assumption in cognitive psychology (Read 2000: 160) that there is a relationship between word frequency and word familiarity, Jensen (2009: 69) suggests that word frequency can be used to estimate the relative amount of effort needed to process a given word: "(..). the more frequently a word occurs in a language, the more likely it is to be known to the recipient ..."

Less frequent words, i.e. words that occur less often than high-frequency words, are expected to demand more cognitive resources than high-frequency words, which are more familiar to the reader. Evidence from psycholinguistic experiments has shown that lexical retrieval time and word frequency correlate as less frequent words are retrieved more slowly than high-frequency words (e.g. Hasher and Zacks 1984). In the present study, the words in the experimental texts were grouped according to frequency: one group consisted of high-frequency words and one group consisted of less frequent words.[19] Less frequent words were defined as words that are among the 1,001-10,000 most frequent words (K2-K10 words). High-frequency words were defined as words that are among the 1-1,000 most frequent words (K1 words). In Figure 4b below, the number of less frequent words is compared with the number of high-frequency words in the three experimental texts.

[19] Word frequencies are based on the British National Corpus [accessed 9 March 2010 from http://www.lextutor.ca/vp/bnc/].

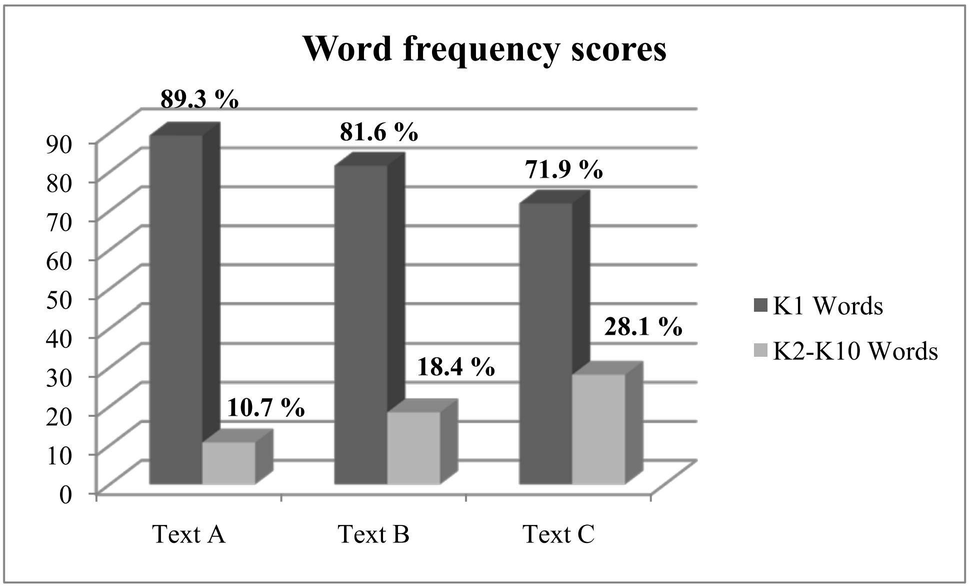

Figure 4b: Word frequency scores of TextA, TextB and TextC

TextA was found to contain the smallest number of less frequent words, (10.7 percent), while TextC contained 28.1 percent less frequent words. TextB fell in between TextA and TextC at 18.4 percent less frequent words. The word frequency measurements indicated that there would be an increase in processing effort when processing TextC relative to TextA.

It should be mentioned that the use of these two groups of frequency bands (K1 and K2-K10) as reflections of source text difficulty is not entirely unproblematic since words that belong to the K2-K10 bands may indeed not be perceived as being particularly difficult compared to words which belong to the K1 band. For instance, the word *below* belongs to the general K2-K10 frequency band. It is unlikely that a translator would consider this word problematic in terms of its translation. It was considered an option to separate frequency bands at the 2000 most frequent words or at the 4000 most frequent words, so that the high-frequency band would include the 2000 or 4000 most frequent words, respectively. However, these high-frequency bands would most likely have illustrated the same trend as the one illustrated in Figure 4b, namely that the number of less frequent words increases from TextA to TextB to TextC.

Non-literalness

The number of non-literal expressions in a text is suggested by Jensen (2009: 61) as an indicator of a text's relative level of complexity. In this study, three types of non-literal expressions were used to measure non-literalness: idioms, metaphors, and metonyms. With respect to employing idioms as an indicator of non-literalness, Jensen (2009: 71) notes that *"(...) the meaning of this type of multi-word expression (idioms) must be known to the hearer or reader as a whole in order for them to interpret it correctly."* Metaphors and metonyms are also types of non-literal expressions in the sense that the meaning of these expressions is not necessarily identifiable based on their constituent(s) but has to be interpreted in context (e.g. Black 1981, Glucksberg 2001). A relationship was therefore assumed between a text's level of non-literalness and its level of difficulty as experienced by the recipient; a high number of non-literal expressions in a text was expected to demand relatively more cognitive resources than a low number of non-literal expressions.

This third complexity criterion also showed an increase in the level of complexity; TextA contained just one non-literal expression against 15 non-literal expressions in TextC, TextB contained nine non-literal expressions (see Table 4a):

Table 4a: Non-literal expressions in TextA, TextB and TextC

TextA	*TextB*	*TextC*
1: Only the awareness of other hospital staff put a stop to him and to the killings	1: Families have to cough up an extra £1,300	1: Spielberg shows Beijing red card
	2: Prices are racing ahead of salary increases	2: Spielberg pulled out of the Olympics
	3: Hit with increase	3: His withdrawal comes in the wake of fighting
	4: Prices/bills soar	4: Khartoum bears the bulk of the responsibility
	5: Prices (…) have climbed	5: Rattle the Chinese government
	6: Cut interest rates	6: Fighting flaring up
	7: Struggles to keep inflation … under control	7: Has sought to halt
	8: Escalating prices	8: Negative fallout
	9: Government	9: Close ties
		10: Close links
		11: Beijing
		12: China
		13: Sudan
		14: Government
		15: Khartoum

Some metonyms are likely to be easier to translate than others. For instance, Khartoum (meaning the Sudanese government located in the capital Khartoum) would probably translate into Khartoum in Danish also. Similarly, some metaphors and idioms are also easier to translate than others; for instance, 'close ties' could be translated into the Danish expression 'tætte bånd', without much additional effort, as it uses the same semantic inventory to create the image. No attempt was made here, however, at examining and rating the potential level of perceived difficulty of each expression; rather, the progression in numbers of non-literal expressions from TextA to TextB to TextC was considered indicative, or suggestive, of an increase in the perceived level of difficulty by the translator.

Summary and discussion of source text complexity

The level of difficulty of a text is inherently problematic to gauge, as the experience of a text's level of difficulty varies between individuals. A complex text is not necessarily difficult to translate by everyone – this depends very much on the routines, skills and specialisation of the translator (e.g. Jensen 2009: 62-63). However, since a complex text is *often* experienced as a difficult text, these relatively crude measures are proposed as indicators of anticipated source text difficulty. Since TextC was more complex than TextA and TextB according to all of the objective criteria, it was anticipated that TextC would be the most difficult text to translate, and since TextA was less complex than TextB, it was anticipated that TextA would be the least difficult text to translate, cf. Table 4b:

Table 4b: Summary of source text complexity indicators

Level of complexity/ difficulty / ***Indicator***	***Least complex/ difficult***	***Moderately complex/difficult***	***Most complex/ difficult***
Readability	TextA	TextB	TextC
Word frequency	TextA	TextB	TextC
Non-literalness	TextA	TextB	TextC

The set of indicators that has been discussed above in relation to the measurement of source text complexity is not exhaustive. Other indicators could have been employed in order to further gauge the anticipated difficulty of comprehending a source text in translation; for instance, syntactic ambiguity is often associated with difficulty since ambiguous sentences can be interpreted in more than one way; sentence comprehension could require more cognitive resources on the part of the translator as she has to consider several potential interpretations. Nonetheless, the three indicators used in the present study to measure source text difficulty are quite easy to work with, and they are expected to provide a good general indication of differences in the amount of cognitive effort needed to translate a given text.

4.4 Time constraint

An aim of the study is to make observations on the effect of time pressure on the allocation of cognitive resources. Traditionally, fixed time constraints, which are uniform for all participants, have been used in experiments that have investigated a relationship between time pressure and the translation process (see section 2.2.4 above). Bayer-Hohenwarter (2009: 194) refers to this approach as the 'fixed-deadline approach'. The underlying assumption of investigations using the fixed-deadline approach is that all participants in the experiments will feel pressed for time. This turned out not to be the case in some of the experiments reported in section 2.2.4, as not all translators experienced the fixed time constraint as time pressure. To overcome the potential problem of applying fixed time constraints, the present study employed individual or *flexible* time constraints. Individual time constraints are flexible in the sense that each constraint is tailored to the individual participant's translator profile so that participants will have different amounts of time available for translation production. Bayer-Hohenwarter (ibid.) calls this approach the 'individual approach'. Bayer-Hohenwarter suggests that individual deadlines could be identified on the basis of a translator's typing speed. In the present study, a baseline production time for each participant was identified by measuring the amount of time it took to finish the warm-up translation task. By doing so, a flexible time constraint that varies according to the baseline *production* speed was introduced for each participant.

In this study, each participant translated two of the three experimental texts under time constraints while one text was translated under no time constraint. The two time constraint values varied as one level was aimed at being heavily restrictive and one level was aimed at being moderately restrictive. The individual baseline time constraint values for all participants are illustrated in column 'Warm-up' in Table 4c below. Based on the warm-up task time, the two levels of time constraint were calculated: the heavily restrictive 'TimeConstraint85' (TV85) and the moderately restrictive 'TimeConstraint100' (TV100). The condition under which the participant is translating under no time constraint is labelled 'TimeConstraintNone'. At TimeConstraint85, the participants had at their disposal an equivalent of 85 percent of the warm-up task time. At TimeConstraint100, the participants had at their disposal an equivalent of 100 percent of the warm-up task time. At TimeConstraintNone, the participants had at their disposal an unlimited amount of time. The table lists the amount of time each participant spent translating the warm-up text and the amount of time that was available for each participant translating Texts A, B, and C in absolute values (minutes:seconds):

Table 4c: Warm-up task time and time available when working under time constraint

	Warm-up	*TextA*	*TextB*	*TextC*
P1	7:56	TimeConstraintNone	TC100 (7:56)	TC85 (6:45)
P2	6:37	TC85 (5:37)	TimeConstraintNone	TC100 (6:37)
P3	6:12	TC100 (6:12)	TC85 (5:16)	TimeConstraintNone
P4	7:03	TimeConstraintNone	TC100 (7:03)	TC85 (6:00)
P5	7:42	TC85 (6:33)	TimeConstraintNone	TC100 (7:42)
P6	8:17	TC100 (8:17)	TC85 (7:02)	TimeConstraintNone
P7	5:58	TimeConstraintNone	TC100 (5:58)	TC85 (5:03)
P8	5:09	TC85 (4:22)	TimeConstraintNone	TC100 (5:09)
P9	3:00	TC100 (3:00)	TC85 (2:33)	TimeConstraintNone
P10	8:20	TimeConstraintNone	TC100 (8:20)	TC85 (7:05)
P11	7.45	TC85 (6:35)	TimeConstraintNone	TC100 (7:45)
P12	7:49	TC100 (7:49)	TC85 (6:38)	TimeConstraintNone
S1	6:02	TimeConstraintNone	TC100 (6:02)	TC85 (5:07)
S2	13:50	TC85 (11:46)	TimeConstraintNone	TC100 (13:50)
S3	4:30	TC100 (4:30)	TC85 (3:50)	TimeConstraintNone
S4	5:12	TimeConstraintNone	TC100 (5:12)	TC85 (4:25)
S5	8:20	TC85 (7:05)	TimeConstraintNone	TC100 (8:20)
S6	6:35	TC100 (6:35)	TC85 (5:35)	TimeConstraintNone
S7	4:58	TimeConstraintNone	TC100 (4:58)	TC85 (4:13)
S8	9:28	TC85 (8:02)	TimeConstraintNone	TC100 (9:28)
S9	4:48	TC100 (4:48)	TC85 (4:05)	TimeConstraintNone
S10	9:24	TimeConstraintNone	TC100 (9:24)	TC85 (7:59)
S11	7:45	TC85 (6:35)	TimeConstraintNone	TC100 (7:45)
S12	6:39	TC100 (6:39)	TC85 (5:39)	TimeConstraintNone

The table shows that the participants' warm-up task times varied considerably: the slowest participant (S2) finished her translation in 13 minutes and 50 seconds, while the fastest participant (P9) finished her translation in 3 minutes flat. If a fixed time constraint had been imposed that was uniform for all participants, for example 5 minutes, S2 would most likely have felt the effects of time pressure very strongly, while P9 most likely would not have felt pressured at all. By the flexible time constraint, S2 had 11 minutes and 46 seconds to translate TextA and P9 had 2 minutes and 33 seconds to translate TextB. It was thus anticipated that both participants experienced more or less the same level of time pressure.

4.4.1 Time constraint value identification

The two time constraint values (TimeConstraint100 and TimeConstraint85) were identified in a pilot experiment. Prior to the main experiment, four participants (two professional translators and two student translators) were tasked with translating Texts A, B and C without time constraints. The objective of that experiment was twofold: (1) to examine if an increase in total production times occurred from TextA, through TextB to TextC, and (2) to examine at what time constraint (as a percentage of the warm-up text's total production time) the participant would be short of time if a time constraint had been imposed. Table 4d below lists the total translation production time for the four participants in the pilot experiment along with differences in production time as a percentage of the time it took to translate the warm-up text:

Table 4d: Total production times in the pilot experiments[20]

	Warm-up	*TextA*	*TextB*	*TextC*
Pilot_par1	7:18	8:03 (+10.5 percent)	12:18 (+68.6 percent)	14:26 (+97.7 percent)
Pilot_par2	7:30	7:08 (-4.9 percent)	8:24 (+17.7 percent)	8:58 (+6.7 percent)
Pilot_par3	13:22	14:55 (+11.7 percent)	17:21 (+16.3 percent)	21:24 (+23.3 percent)
Pilot_par4	7:42	6:37 (-14.1 percent)	7:55 (+19.6 percent)	11:36 (+46.5 percent)
Mean	8:58	9:11 (+2.4 percent)	11:29 (+28.2 percent)	14:06 (+57.2 percent)

Considering first the means in the bottom row, TextA was translated in more or less the same time as the warm-up text. TextB required around 2½ minutes more time and TextC required around 5 minutes more time. In the pilot experiment, it was thus found that there was a progression in total production time, which correlated with source text complexity. Comparing mean production time of TextA with mean production time of the warm-up text, there was only a small difference. Production time for TextB was 28 percent greater, while TextC production time was 57 percent longer. It was assumed that under the most restrictive time constraint (TimeConstraint85), the participant would experience time pressure irrespective of the level of source text complexity, while the experience of time pressure under the less restrictive time constraint (TimeConstraint100) would only be felt during the translation of TextB and TextC.

[20] Participants in the pilot experiment were each given a number preceded by the designation 'Pilot_par'.

4.5 Presentation sequence of the source texts

Semi-randomised presentation sequences of the source texts were introduced in order to minimise the risk that observations (in part) had to do with a repeated presentation sequence. In the presentation sequence design used in this study, each of the three experimental texts under each of the three time constraint conditions (which equal nine combinations of source text complexity and time constraint) was systematically presented an equal number of times in different positions. The design used in the present study was arrived at heuristically by testing and rejecting potential presentation designs. The first design that was tested was the so-called ‘default’-design:

Table 4e: Default presentation sequence[21]

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
Initial	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Medial	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B
Final	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C

In the ‘default’ design shown in Table 4e above, all participants would translate the easy TextA first and finish by translating the difficult TextC. The time constraint values would be introduced so that the first text would be translated under no time pressure, the second text under moderate time pressure and the third text under heavy time pressure. This design was rejected since the three experimental texts A, B, C each would be translated under the same time constraint, i.e. TimeConstraintNone, TimeConstraint100 and TimeConstraint85, respectively in the same position (initial, medial or final). Another design was therefore considered. The model below illustrates the presentation sequence in which the levels of the two factors were rotated: each text was rotated clockwise one step from one participant to the next, and each time pressure value was rotated counter-clockwise one step from one participant to the next.

[21] Colour codes: ‘White’ = *No time constraint*, ‘light grey’ = *100 percent time constraint*, ‘dark grey’ = *85 percent time constraint*. Letter codes: ‘A’ = *TextA*, ‘B’ = *TextB*, ‘C’ = *TextC*.

Table 4f: Rotation of individual presentation sequences

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
Initial	A	C	B	A	C	B	A	C	B	A	C	B	A	C	B	A	C	B	A	C	B	A	C	B
Medial	B	A	C	B	A	C	B	A	C	B	A	C	B	A	C	B	A	C	B	A	C	B	A	C
Final	C	B	A	C	B	A	C	B	A	C	B	A	C	B	A	C	B	A	C	B	A	C	B	A

Each experimental text and each time pressure value would now be presented a uniform number of times in initial, medial and final positions. TextA would be presented as the first text eight times, TimeConstraintNone would be presented as the first time pressure value eight times, etc. This design was nevertheless also considered flawed as each text/time-combination is not distributed evenly across initial, medial and final positions. For instance, TextA translated under TimeConstraintNone would always be presented in initial position, TextB translated under TimeConstraint100 would always be presented in medial position, etc. A third design was therefore considered, which takes into account this flaw; 'blocks' of nine translations were rotated clockwise as illustrated in Table 4g. By this approach, texts/time conditions that would occur only in initial, medial or in final positions now also occur in other positions:

Table 4g: Rotation of groups of presentation sequences

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
Initial	A	C	B										A	C	B									
Medial	B	A	C	A	C	B							B	A	C	A	C	B						
Final	C	B	A	B	A	C	A	C	B				C	B	A	B	A	C	A	C	B			
Initial				C	B	A	B	A	C	A	C	B				C	B	A	B	A	C	A	C	B
Medial							C	B	A	B	A	C							C	B	A	B	A	C
Final										C	B	A										C	B	A

By applying the above design, TextA under no time pressure would then occur in initial position four times, medial position twice and final position twice. TextB under moderate time pressure would occur in medial position four times, in final position twice and in initial position twice, etc. Ideally, each combination of TextComplexity and TimeConstraint occurred in each position three times. However, the current design is considered sufficiently reliable in providing a framework in which combinations of texts and time pressure values are randomised across all participants.

The design presented in Table 4h below shows the actual presentation sequence which was used in this study. It differs slightly from the design presented in Table 4g above as five participants (P10, P11, P12, S11 and S12) were given presentation sequences that were not in agreement with the proposed design. It is not expected that this deviation will have much impact on the overall reliability of the study's results as most of the presentation sequences are in agreement.

Table 4h: Actual presentation sequence

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
Initial	A	C	B	C	B	A	B	A	C	C	B	C	A	C	B	C	B	A	B	A	C	A	B	A
Medial	B	A	C	A	C	B	C	B	A	A	C	A	B	A	C	A	C	B	C	B	A	B	C	B
Final	C	B	A	B	A	C	A	C	B	B	A	B	C	B	A	B	A	C	A	C	B	C	A	C

An alternative to this complex design was considered in which data would be collected by setting up two independent experiments: one experiment, which examines only the effects of text difficulty, and another experiment, which examines only the effects of time pressure. Data collection by such two-part design would be relatively simpler; however, it would pose some challenges if the same participants took part in both experiments. Then the experimenter would need to manipulate two sets of texts (2x3) instead of only one, so that the participants would not translate the same text twice. The two sets of texts would have to be comparable in terms of source text complexity, which is challenging by any measure. If instead the one set of texts was used in both experiments, the design would require two groups of participants, who are comparable on multiple parameters such as area of expertise, preferred language direction, years of experience, educational background, etc. Achieving a high level of group comparability was also expected to be quite challenging.

Although the experimental randomisation design that is used to collect data in the present study is far more complex than the alternative presented above, it is expected that this final design will yield the most easily comparable data.

Chapter 5

Data collection, preparation, coding and analysis

5.1 Data collection

Two types of translation process data were collected in the experiments. Eye-tracking data were collected with Tobii's 1750 remote eye tracker and Tobii's data collection/analysis software ClearView. Key-logging data were obtained using the Tobii eye tracker/ClearView and the Translog software (Jakobsen and Schou 1999). In this study, eye-tracking and key-logging data from the 1750 eye tracker/ClearView were analysed. Key-logging data from Translog were not subjected to analysis. The analyses of this study (particular that of AU duration) relied on a high degree of temporal synchronism between eye-tracking data and key-logging data, which must be aligned with millisecond precision in order to reflect the actual AU duration as correctly as possible. Achieving a high degree of temporal synchronisation of Tobii's eye-tracking data and Translog's key-logging data is complicated and possibly prone to error since data from two independent sources would have to be merged. By using data from the same equipment, a higher degree of temporal synchronisation can be achieved since the two data streams rely on the same time stamp generator.

Translog was used to display the source texts and the emerging target texts. The upper part of the Translog program window (i.e. the ST window) displayed the STs, and the participants typed their translations in the lower part of the program window (i.e. the TT window). The STs were displayed in 18-point Tahoma and double line spacing on a 17" LCD monitor at 1280 x 1024 pixels. Text in the TT output window was also displayed in 18-point Tahoma but in single line spacing. The version of the Translog software (version 3.2.5.0.) that was used in this experiment does not permit double line spacing in the TT output window. In future experiments, double line spacing in both ST and TT windows would be preferred, since it improves the comparability in the analyses between ST and TT eye movement data, as well as it improves the reliability of the analyses of the TT eye movement data.

5.1.1 Eye tracking system

The Tobii 1750 eye tracker is a video-based remote eye tracker, which is disguised in appearance as a regular computer monitor. Built-in diodes around the edge of the monitor generate near-infrared beams that are reflected on the cornea of a user's eyes. A camera, located just below the screen, captures the corneal reflection and then calculates the position of the gaze on the screen. Measurements by the 1750 eye tracker are accurate to 0.5 of a degree, which corresponds to up to 1 cm of inaccuracy. This degree of inaccuracy places restrictions on the research design in terms of the necessity of displaying the experimental texts with larger fonts than would have been used in most other translation situations. Other types of eye trackers (e.g. SMI's iView X Hi-speed and SR Research's EyeLink 1000 Head Supported) work at higher temporal and spatial resolutions. Often, however, they require that the position of the participant's head is kept relatively still, which is undesirable in a naturalistic experiment such as the present (see section 3.3.1 above for a discussion of different types of eye trackers).

The Tobii 1750 runs at 50 Hz, which means that Tobii/ClearView records eye movement data every 20 milliseconds. Tobii/ClearView records the position of the participant's gaze on the screen, the size of the pupils, the participant's distance to the monitor, and the participant's gaze angle to the monitor. Key and mouse events are also recorded when the participant presses a keyboard key or presses the left or right mouse buttons.

5.1.2 Quality of eye-tracking data

The quality of eye-tracking data is sensitive to several factors: participants' optical aids, varying lighting conditions, user's distance from the monitor, etc. (cf. e.g. O'Brien 2009: 253). To minimize the implications of some of these potentially error-inducing factors, various measures were taken: curtains were drawn to reduce the amount of natural light; the same artificial light (a desktop lamp) was lit during all experiments, the eye tracker was placed on a separate table with which the study's participants had no direct contact in order to minimize the risk of vibration to the eye tracker; the participants sat in a fixed chair, so that they would not easily move about and potentially increase the distance to the monitor (they were seated between 55 cm and 65 cm from the eye tracker).

In spite of taking these precautions, recordings were still at risk of containing data that incorrectly reflected the participants' actual eye movements and pupillary movements. In the present study, the quality of the recorded eye-tracking data was assessed by applying three data quality criteria: (1) Gaze Time on the Screen as a percentage of total production time (GTS), (2) Gaze sample to Fixation Percentage (GFP), and (3) Mean Fixation Duration (MFD). Recordings were included in the study if the quality analysis revealed that they met the requirements of at least two of the three criteria. Recordings in which two or three criteria were not met were thus excluded (See Appendixes D1, D2 and D3).

Gaze time on screen (GTS)

In a study that relies on eye-tracking data, sufficient amounts of data must be available for analysis. The amount of gaze time on the computer screen as a percentage of the total production time (GTS) is suggested as a criterion for evaluating eye-tracking data quality since it gives the experimenter an indication of the amount of eye-tracking data that has been recorded during the experiment.

GTS scores were calculated for each participant by comparing the sum of all fixations during drafting to the total drafting time *(100 / total drafting time x fixation sum)*. As an example, P6 drafted her translation of TextC in 206 seconds; in this time span, she gazed at the screen for 158 seconds, which produces a GTS score of 76.7 percent. At the other end of the scale is participant D2. D2 drafted her translation of TextA in 257.6 seconds; during this time, she spent only 33.2 seconds gazing at the screen, equalling a GTS score of just 12.9 percent. A recording in which was registered a total of 33.2 seconds of gaze time was not considered likely to reliably reflect the participant's actual eye movements; the participant would most likely have needed much more time to read the 148 ST words and possibly also read her written TT output. Translation drafts that scored GTS scores lower than one standard deviation (SD) (32.7) below the mean of the study's 81 translations were *flagged*, as shown in Table 5a below (GTS mean = 55.7 percent, SD = 23.0).

Table 5a: Recordings which contained flagged GTS scores (grey cells)

	TextA	TextB	TextC
P4	29.1	30.6	29.4
P6	36.1	31.9	41.2
S2	28.1	32.8	37.6
S12	34.6	32.3	38.3
D1	0.9	1.4	1.7
D2	9.1	85.6	1.1
D3	21.5	47.5	38.0

Of the 81 translation drafts, 12 (14.8 percent) had GTS scores that were lower than one SD below the mean of the 81 translations. The most extreme example was D1's drafting of TextA, TextB and TextC, during which the sum of her fixations represented respectively 0.9 percent, 1.4 percent and 1.7 percent of the total drafting time, or around 11 seconds for all three texts. For some reason, the data recorded during her translation drafting reported very little gaze activity. This is probably not a true representation of her eye movements, since she managed to translate all three texts (a total of 419 ST words). A more likely explanation is that the eye-tracking data are flawed for some reason.

Gaze sample to fixation percentage (GFP)

In reading, 85 to 95 percent of all eye movements are fixations while the remaining 5-15 percent are saccades (see section 3.3.1.2 above). The gaze sample to fixation percentage (GFP) is here suggested as a criterion for evaluating eye-tracking data quality as it reflects how much of a participant's gaze activity actually belongs to fixations and how much does not. The Tobii 1750 and ClearView do not specify the amount of saccadic eye movements in a recording. However, in ClearView's data log files, gaze sample rows that have been left unassigned when ClearView automatically calculated the fixations can be located. Logically, these unassigned data sample rows should be categorised only as saccades, since reading involves only fixations and saccades (see section 3.2.1 above), and they should accordingly account for only 5-15 percent of the total gaze activity. A saccade percentage that is higher than this would indicate that *some* of the gaze sample rows do not reflect fixational or saccadic eye movements; they rather reflect noise in the eye-tracking data.

GFP scores were calculated for all participants by comparing the total number of gaze samples with the number of gaze samples that formed part of a fixation: (*100 / number of gaze samples X number of fixation gaze samples)*. For instance, in P9's translation draft of TextA, 10,207 gaze samples were recorded. Of those, 9,566 gaze samples belonged to fixations, equalling a GFP score of 93.7. It follows that 93.7 percent of her gaze sample rows belonged to fixations, while 6.3 percent did not. This is comfortably within the 85-95 percent fixation range reported above. Another example is D3's translation of TextB: 15,009 gaze samples were recorded, and of those, 8,478 gaze samples belonged to fixations, equalling a GFP score of 56.5. This means that 43.5 percent of all gaze sample rows constitute gaze activity that cannot be categorised as fixations. Assuming that 15 percent of the sample rows belonged to saccadic eye movements, 28.5 percent of all gaze sample rows are still unaccounted for, as they did not belong to fixations or saccades.

Ideally, the present study would only have included data from translations in which the GFP score was equal to or higher than 85 percent and excluded translations in which the GFP score was lower than 85 percent. Since the quality of eye-tracking data is prone to be affected by external factors such as those described earlier, irrespective of the efforts made to minimise them, an 85 percent threshold would disqualify nearly half of the participants' recordings (48.1 percent). The present study therefore adopted a lower threshold at 75 percent. By this threshold, only 10 percent (*85 percent – 75 percent*) of the gaze samples cannot be categorised as fixation gaze samples or saccade gaze samples, but rather as noise. Table 5b below lists translation drafts in which the GFP scores were lower than 75 percent:

Table 5b: Recordings which contained flagged GFP scores (grey cells)

	TextA	TextB	TextC
P5	79.7	81.2	74.0
S2	71.2	69.1	81.0
S11	76.3	72.6	78.2
D1	21.7	58.6	46.3
D2	79.3	94.5	26.0
D3	56.5	54.5	56.1

Of the 81 translation drafts by 27 participants, 11 translation drafts (13.6 percent) scored lower than 75 percent by the GFP criterion and were flagged. The scores for four of those 11 translations were just below the 75 percent threshold, while seven were well below.

Mean fixation duration

As noted in section 3.3.1.1, fixations during reading mostly last between 225 and 400 ms. Recordings in which the mean fixation duration (MFD) was lower than 200 ms[22] could be (partially) corrupted in that the short fixations could reflect noisy data rather than a low amount of cognitive effort invested during a given task. Mean fixation durations were calculated by dividing the combined fixation duration by the number of fixations in a translation. Table 5c below displays the translation that had a mean fixation duration that was shorter than 200 ms:

Table 5c: Recording which contained a flagged MFD score (grey cell)

	TextA	TextB	TextC
D2	280 ms	364 ms	186 ms

Of the 81 translations by 27 participants, only one translation draft (1.2 percent) had a mean fixation duration that was below 200 ms. Although just one translation draft scored lower than the 200 ms mean fixation duration threshold, the criterion is still considered a relevant indicator of eye-tracking data quality. One possible explanation why just one

[22] A lower boundary of 200 ms was used here rather than the 225 ms lower boundary reported by Rayner (1998: 373) in order to take into account imprecision by the eye tracking equipment.

translation draft did not meet the requirement by this criterion is that the precautionary measures intended to reduce the amount of flawed data were successfully implemented. In an earlier experiment using eye tracking carried out in 2007 (reported in Pavlović and Jensen 2009: 99), 50 percent (8 participants of 16) of all the experiment's recordings were discarded due to abnormally short mean fixation durations (< 200 ms). It was speculated that the short fixation durations found in some participants' recordings were caused by problems with the eye tracking hardware. It is more likely, however, that the short fixation durations had to do with problems in the experimental setup, e.g. that the participants were seated too far away from the monitor. The fact that only one translation draft in the present study fell below the 200 ms threshold highlights the importance of taking precautionary measures when carrying out experiments using eye tracking.

Summary and discussion of quality of eye-tracking data

Table 5d below summarises the results from the eye-tracking data quality analyses. Light grey cells illustrate that the requirement of one criterion has not been met. Dark grey cells illustrate that the requirements of two or more criteria have not been met:

Table 5d: Summary of eye-tracking data quality analyses

Text	TextA			TextB			TextC		
Criteria / Participant	GTS	GFP	MFD	GTS	GFP	MFD	GTS	GFP	MFD
P6				x					
P4	x			x			x		
P5								x	
S2	x	x			x				
S11					x				
S12				x					
D1	x	x		x	x		x	x	
D2	x						x	x	x
D3	x	x			x			x	

The table shows that 17 translations[23] did not meet the requirements of at least one of the three quality criteria. Five of the translations (in bold) were excluded from the analyses carried out in Chapter 6 as they did not meet the requirements by two or three criteria. For reasons of comparability, the analyses of Chapter 6 required that the quality of *all* three translations of a participant must fall within range of acceptability by the quality criteria. Since D2's translation of TextC and D3's translation of TextA failed to meet the requirements of two criteria, their translations of TextA and TextB, and TextB and TextC, respectively, were also excluded.

In summary, the discard percentage is 11.1. Compared to a similar experiment carried out with the same equipment and at the same facilities (Pavlović and Jensen 2009, also reported above), this percentage is low. The main reason for the low discard percentage in the present study is probably that all experiments have been carried out under the strict experimental conditions described in the beginning of this section. Furthermore, in the Pavlović and Jensen experiment, only one criterion was used to examine eye-tracking data quality, as noted above, viz. mean fixation duration. The present study's quality analysis clearly demonstrates that the mean fixation duration criterion must be complemented with analyses by other criteria, such as GTS and GFP. Had the present study relied on the MFD criterion alone, it would have included data that did not reliably reflect the participants' actual eye movements.

5.1.3 Eye tracking software and key logging software

Tobii's eye tracking software ClearView (version 2.7.1.) was used to prepare and execute the experiments. ClearView's user interface is divided into three modules: Prepare, Record, and Analyze. The recording procedure is explained below:

5.1.3.1 Experiment preparation

In ClearView's preparation module, *Screen* was selected as the type of stimulus for the study. Using the *Screen* setup, any changes to the screen image are recorded in an .avi

[23] The data from S2's translation of TextA also did not meet the requirements of two criteria (i.e. GTS and GFP); however, S2's translations were still included in the study. The inclusion of her data was due to a miscalculation of the GFP which showed that the text scored above the threshold of 75 percent; it turned out later that the GFP score was in fact lower (71.2 percent). At the time of discovery of the miscalculation, the analyses in Chapter 6 had already been carried out, and the analyses were not redone, since her GFP score and GTS score (28.1 percent) fell only marginally below thresholds.

video file while all eye movements, pupillary movements, typing and mouse events are stored in separate data files. Other stimulus options include *Image*, in which the same static image is presented on the screen for a predefined period of time, and *Slideshow*, in which multiple images are presented in succession at predefined time intervals. Both of these types of stimuli are used in studies in which the user remains passive throughout the experiment as she does not engage in activities that change the image on the screen (for example in reading experiments, picture description experiments etc.). Although the ST remains static throughout a translation experiment, the user changes the image on the screen by typing TT output which emerges on the computer screen. The *Screen* stimulus was therefore considered the only suitable stimulus type. In the preparation module, the names of the participants in the study were entered.

5.1.3.2 Recording

In the recording module, a mandatory calibration was performed for each of the study's participants prior to each experiment. ClearView uses the calibration data to estimate the participant's gaze point as accurately as possible.[24] Typically, only one calibration is needed per participant. This means that the calibration that was carried out prior to the warm-up task was reused for the experimental texts.

During calibration, the participant was asked to look at a calibration object, which moved between five calibration points; four points were located near the corners of the screen and one was located at its centre. When the calibration session was completed, a calibration plot was displayed. The calibration plot may be used as an indicator of the quality of the calibration and thus as an indicator of the eye-tracking data quality of the pending experiment. A high quality calibration, during which ClearView has collected sufficient data for good gaze point estimation, is indicated by short red and green lines extending from all calibration points (or preferably observable only as dots within each calibration point). A calibration of lesser quality is indicated by no red and green lines extending from one or more calibration points or by long red and green lines extending from the calibration points. ClearView will suggest recalibration of one or more calibration points if the calibration quality is poor.

Earlier experiments (e.g. Jakobsen and Jensen 2008, Pavlović and Jensen 2009) conducted with the same eye tracker suggest that eye-tracking data quality is sensitive to the quality of the calibration. Although ClearView in many cases did not suggest recalibration, calibration was accepted by the experimenter only if very short lines

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[24] ClearView User Manual. Tobii Eye Tracker. ClearView analysis software. Version 2.7.

(< 5 mm) or dots were observed within or immediately outside the calibration points. This meant that calibration had to be repeated several times for some participants, until a satisfactory calibration had been secured.

Once an acceptable calibration was saved, the recording was started. ClearView's user interface was automatically minimised and ran in the background while the participant translated the warm-up text and the three experimental texts. The recording was terminated by pressing F10.

5.1.3.3 ClearView analysis

ClearView's analysis module was used to organise the data and to export the log files for later analysis.

Study settings

For experiments that involve mostly reading, ClearView suggests that the fixation filter[25] is set to 20 pixels (fixation radius) and 40 ms (minimum fixation duration). At this setting, at least three gaze point registrations must be no farther apart than 20 pixels from each other, in order to be considered part of the same fixation. Initially, this recommended setting was applied to calculate fixations in the present study; however, it turned out that mean fixation duration in all of the participants' recordings fell well below the 225 ms mean which Rayner (1998: 373) reports is the typical fixation duration during normal reading (see also sections 3.3.1.1 and 5.1.2). Instead, a different fixation filter setting was applied, which turned out to result in fewer abnormally short fixations. The fixation radius for this setting was set to 40 pixels and the minimum fixation duration was set to 100 ms. This fixation filter setting is also recommended by the EYE-to-IT project, following several pilot studies and tests with other filter settings; it is pointed out, however, that the minimum fixation duration setting could be set as low as 80 ms (Gerganov 2007). Having applied the setting of 40 pixels and 100 ms, overall mean fixation duration for all 24 participants' recordings included in the study across the three experimental texts was 304 ms (range: 204 ms ~ 490 ms). Mean fixation during ST reading was 238 ms (range: 181 ms ~ 316 ms) and 370 ms during TT reading (range: 204 ms ~ 651 ms).

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[25] The fixation filter groups gaze samples according to the physical distance between samples and the time span between samples.

Scene definition

Section 3.2 discussed the three stages of translation: 'orientation', 'drafting' and 'revision'. This study will concern only cognitive resources that are allocated to the drafting of the translation, i.e. the drafting stage. For this reason, ClearView's 'Scene Tool' was used to assign different 'Drafting Scenes' to each participant's translations of the three texts. A scene is basically a selection of the participant's recording that is defined by a beginning and an end on a continuum. Data analysis will thus be based only on the data contained within the specified scene. Drafting scenes were defined as spanning from the time when text production began, i.e. at the first press on the keyboard, and ended upon completion of the last sentence, typically as indicated by the last full stop (see also section 3.2 for an overview of Jakobsen's (2002) operationalisation criteria). A total of 72 scenes (one for each translation) were defined for the study's analyses reported in Chapter 6.

AOI definition

The *Define AOIs* tool allows the experimenter to define which area(s) (AOI = Area of Interest) on the screen are included in the data analyses. In ClearView, AOIs are created by dragging a rectangular or polygonal shape around the area that the experimenter wishes to have included in an analysis. The corners of the AOIs are defined by the pixel position relative to the top-left corner, and data analysis carried out from within ClearView will include only data contained within the specified AOI of a given scene.

For the purposes of this study, two AOIs were created. The first AOI was labelled *ST*, and it covered the ST area of the screen. The second AOI was labelled *TT*, and it covered the TT area of the screen. Since ClearView's AOI definition tool defines the AOI borders somewhat inaccurately, the corners of the two AOIs were adjusted manually using a text editor outside the ClearView environment so that the AOIs would border each other without overlapping. Horizontally, both ST AOIs and TT AOIs extended from the left edge of the screen to the right edge of the screen (from pixel position 0 to pixel position 1280 on the X-axis). Vertically, the ST AOIs extended from pixel position 75 to pixel position 560 on the Y-axis, and the TT AOIs extended from pixel position 561 to pixel position 972 on the Y-axis. Information about the pixel position of the AOIs was used to annotate the eye-tracking data (see section 5.2.2).

5.2 Data preparation and coding

As established earlier, three investigations were carried in this study, using three indicators of cognitive resource allocation: TA duration (*research question **R1***), AU duration (*research question **R2***) and pupil size (*research question **R3***). ClearView does not provide the figures necessary to carry out the analyses needed for the investigations using AU duration and pupil size. Due to these limited capabilities of ClearView, separate calculations of the eye-tracking and key-logging data were performed with the purpose of making available the necessary figures.

Although ClearView's analysis tool in fact provided the aggregate figures that were needed for the investigation of research question **R1**, the present study relied on calculations of TA duration in the R environment (see section 5.3) as TA duration figures were readily available by multiplying AU duration figures.

5.2.1 ClearView's data log files

To make available the necessary figures, data log files (.txt) of the participants' recordings were exported from ClearView, and the spreadsheet program Excel was used to prepare each log file for annotation. Two types of sample rows are represented in ClearView's exported log files: (1) gaze data sample rows, and (2) key/mouse data sample rows. Each gaze sample row contains information for both eyes about the X-Y coordinates of the participant's gaze on the screen (i.e. the pixel position of the gaze), the eye-camera angle, the participant's distance to the monitor, pupil size, and the X-Y coordinates of the participant's fixations, as estimated by ClearView. The key/mouse data sample rows contain information about which key has been pressed at what time, information about the mouse's cursor position when either the left or the right mouse button is pressed or they are blank in the event no key/mouse events are registered. Both types of sample rows contain time stamps. Table 5e below is an extract of ClearView's data log file:

Table 5e: Example of a ClearView log file

Timestamp	Number	GazepointX (L)	GazepointY (L)	CamX (L)	CamY (L)	Distance (L)	Pupil (L)	Validity (L)	GazepointX (R)	GazepointY (R)	CamX (R)	CamY (R)	Distance (R)	Pupil (R)	Validity (R)	Fixation	GazepointX	GazepointY	Event	Event Key	Data 1	Data 2	Description
276179								5							5				Keyboard	3	32	0	Space
276185	13841	578	561	0.859	0.474	537.861	3.088	0	607	531	0.545	0.451	544.899	3.263	0	542	599	531					
276205	13842	577	559	0.856	0.471	538.069	3.094	0	581	527	0.541	0.45	544.899	3.193	0	542	599	531					
276225	13843	580	574	0.852	0.47	537.961	3.108	0	583	541	0.537	0.45	544.899	3.152	0	542	599	531					
276245	13844	575	568	0.848	0.469	537.729	3.025	0	583	529	0.534	0.45	544.899	3.139	0	542	599	531					
276265	13845	581	556	0.845	0.468	537.73	3.038	0	568	531	0.53	0.45	544.899	3.114	0	542	599	531					
276285	13846	584	546	0.841	0.467	545.061	3.091	0	567	537	0.526	0.45	544.233	3.094	0	542	599	531					
276305	13847	588	530	0.838	0.467	545.061	3.028	0	579	534	0.523	0.45	544.233	3.082	0	542	599	531					
276324	13848	590	531	0.835	0.466	545.061	3.013	0	576	540	0.52	0.45	544.233	3.041	0	542	599	531					
276344	13849	588	538	0.833	0.465	545.061	2.96	0	580	516	0.518	0.45	544.233	3.037	0	542	599	531					
276357								5							5				Keyboard	3	84	0	t
276364	13850	587	517	0.831	0.464	545.061	2.937	0	575	513	0.516	0.449	544.233	3.057	0	542	599	531					
276384	13851	586	525	0.828	0.463	541.947	2.899	0	575	508	0.513	0.448	545.604	3.068	0	542	599	531					
276404	13852	589	548	0.826	0.461	541.947	2.911	0	586	520	0.511	0.447	545.604	3.017	0	542	599	531					
276424	13853	592	517	0.824	0.459	541.947	2.886	0	578	516	0.509	0.445	545.604	2.945	0	542	599	531					
276444	13854	586	537	0.821	0.458	541.947	2.878	0	585	518	0.506	0.444	545.604	2.979	0	542	599	531					
276456								5							5				Keyboard	3	69	0	e
276464	13855	579	543	0.818	0.457	541.947	2.852	0	580	518	0.503	0.444	545.604	2.982	0	542	599	531					
276484	13856	577	528	0.815	0.455	543.75	2.847	0	583	516	0.5	0.443	546.539	2.99	0	542	599	531					
276504	13857	590	533	0.812	0.454	543.75	2.795	0	578	511	0.497	0.442	546.539	2.927	0	542	599	531					
276524	13858	587	541	0.81	0.453	543.75	2.862	0	581	522	0.494	0.442	546.539	2.9	0	542	599	531					
276544	13859	591	534	0.807	0.453	543.75	2.818	0	577	514	0.492	0.442	546.539	2.909	0	542	599	531					
276564	13860	591	534	0.805	0.452	543.75	2.793	0	579	526	0.49	0.442	546.539	2.846	0	542	599	531					
276584	13861	590	535	0.803	0.452	543.178	2.812	0	580	525	0.488	0.442	545.885	2.828	0	542	599	531					
276604	13862	585	546	0.801	0.452	543.178	2.745	0	583	517	0.486	0.442	545.885	2.894	0	542	599	531					
276623	13863	593	539	0.799	0.451	543.178	2.74	0	577	524	0.483	0.442	545.885	2.858	0	542	599	531					
276628								5							5				Keyboard	3	75	0	k
276643	13864	589	540	0.797	0.451	543.178	2.729	0	574	514	0.481	0.443	545.885	2.804	0	542	599	531					
276663	13865	590	543	0.795	0.451	543.178	2.736	0	577	511	0.479	0.443	545.885	2.834	0	542	599	531					
276683	13866	589	540	0.793	0.452	542.91	2.73	0	575	507	0.477	0.444	548.154	2.819	0	542	599	531					
276703	13867	589	541	0.791	0.452	542.91	2.757	0	579	506	0.476	0.445	548.154	2.833	0	542	599	531					
276723	13868	591	539	0.79	0.452	542.91	2.69	0	576	508	0.475	0.445	548.154	2.808	0	542	599	531					
276724								5							5				Keyboard	3	83	0	s
276743	13869	601	537	0.788	0.452	542.91	2.673	0	584	513	0.473	0.446	548.154	2.849	0	542	599	531					
276763	13870	604	539	0.787	0.452	542.91	2.688	0	586	508	0.473	0.446	548.154	2.822	0	542	599	531					
276783	13871	607	535	0.787	0.452	544.63	2.69	0	587	513	0.472	0.447	546.994	2.813	0	542	599	531					
276803	13872	608	535	0.786	0.452	544.63	2.707	0	585	511	0.471	0.447	546.994	2.854	0	542	599	531					

5.2.2 Data annotation

ClearView does not provide indication of the type of cognitive activity that is occurring during a specific sample row (i.e. ClearView does not tell if the participant is looking at the ST or at the TT). ClearView's log files only provide the X-Y coordinates of the location of the eyes on the screen at a given time in addition to information about typing events. Excel formulas were therefore designed and implemented within each participant's log files. The objectives were to identify (1) the location of the gaze (if it was *inside* the ST area, *inside* the TT area, *outside* the ST and TT areas or *outside* the screen area), and (2) if typing was registered or not.

Pixel position data from the gaze sample rows were compared to the coordinates of the two AOIs (i.e. the ST AOI and the TT AOI). As noted in section 5.1.3.3 above, both types of AOIs extend horizontally from the left edge of the screen to the right edge of the screen. Vertically, the AOIs extend from top to bottom according to the pixel positions listed in the left-most column of Table 5f below:

Table 5f: Areas of Interest (AOIs)

Pixel position	Location of gaze
< 0	Gaze off the screen | *'NoGaze'*
> 0, < 74	Gaze on the screen outside ST and TT areas | *'Gaze'*
> 75, < 560	Source text area | *'STgaze'*
> 561, < 972	Target text area | *'TTgaze'*
> 973, < 1024	Gaze on the screen outside ST and TT areas | *'Gaze'*
> 1024	Gaze off the screen | *'NoGaze'*

If the pixel position on the vertical Y-axis (*GazepointY (L)* and *GazepointY (R)*) in a gaze sample row was lower than 0 or greater than 1024 (meaning outside of the screen area), this row was coded as 'NoGaze'.[26] If the pixel position in the gaze sample row was between 0 and 74 or between 973 and 1024, this row was coded as 'Gaze' to illustrate that non-ST and non-TT gaze activity had been registered within the screen area. If the

[26] Although the eye tracker generally only registers eye movement *within* the monitor's screen area, it does infrequently happen that fixations are registered which occur *outside* the monitor's screen area (see also footnote 27).

pixel position was between 75 and 560, the row was coded as 'STgaze', and if the pixel position was between 561 and 972, the row was coded as 'TTgaze'. (The ST and TT areas of the screen represented around 88 percent of the total surface area of the screen.) If no eye movement data were registered, the row was coded as 'NoData'. Finally, if typing activity was registered in a key/mouse sample row, this row was coded as 'Typing'. In addition, the preceding ten sample rows (representing approximately 200 ms of recording) were coded as 'Typing', under the assumption that the initiation of a typing event occurs at least 200 ms before it is registered by the key logging program (see also section 3.3.2).

Having annotated each gaze and key/mouse sample row with information of the type of activity that occurs within it, the AUs were calculated and supplied with duration values and pupil size values.

5.2.3 Attention units (AUs)

As established in section 3.3, eye-tracking and key-logging data can be interpreted as indicators of attention and thus indicators of cognitive resources allocated to a particular task. In line with these assumptions, the present study assumed that the type of activity (allocation of cognitive resources to the ST (STAUs), to the TT (TTAUs) or to the ST and the TT in parallel (PAUs)) annotated in each individual sample row reflected the allocation of cognitive resources to a particular task during the total duration of an AU (see also section 3.3.3).

5.2.3.1 Micro- and macroAUs

In order to identify STAUs, TTAUs and PAUs, *micro*AUs were first calculated by comparing the types of attention that were registered in neighbouring data sample rows (see section 5.2.2). If the same type of attention was annotated in both the current and the preceding sample rows, the two sample rows were collapsed and categorised as belonging to the same continuous microAU. For instance, if the same type of attention (e.g. TTgaze) was annotated in two sample rows, these two sample rows would constitute one TTgaze microAU. This process was carried out for all sample rows.

Several of the categories of microAUs listed in the left column of Table 5g below overlap in the sense that they belong to the same overall category of ST, TT or ST/TT attention. For instance, four of the microAU categories (NoGaze + Typing, GazeOff +

Typing, TTgaze + Typing, TTgaze) all reflect TT attention. These four microAU categories were therefore recategorised and collapsed into one *macro*AU category as illustrated in Table 5g below:

Table 5g: Summary of micro- and macroAU categories

Categories of microAUs	***Categories of macroAUs***
STgaze	STAU
NoGaze + Typing GazeOff + Typing TTgaze + Typing TTgaze	TTAU
STgaze + Typing	PAU
NoData GazeOff	NoData[27]

Since the present study is primarily interested in three categories of attention as reflections of cognitive processing (ST attention, TT attention and parallel ST/TT attention), *macro*AUs were calculated on the basis of the microAUs. In the macroAU categorisation, the four microAU categories were renamed into 'TT macroAU'. In practice, this meant that two microAUs (e.g. TTgaze + Typing and TTgaze, etc.) that neighboured each other in the data log file would be collapsed into one TT macroAU. The same procedure applied for the two microAU categories NoData and GazeOff, which were renamed 'NoData' during macroAU categorisation. They were also collapsed in the event they were adjacent. STgaze microAUs were renamed into 'STAU macroAU' and STgaze + Typing microAUs were renamed into 'PAU macroAU', respectively.

Since the distinction between microAU and macroAU is relevant until now only, macroAU will henceforth be referred to simply as 'AU' (i.e. TTAU, STAU and PAU). Each AU was automatically annotated with an AU duration value. This value was identified by calculating the time interval from the beginning of the AU until the end of the AU. These three types of AUs, annotated with an individual duration value, constituted the data points that were included in the analysis of section 6.2.

[27] NoData AUs contain no eye-tracking or key-logging data. They occur when no typing events or eye movement are registered. In the present study, instances of missing eye-movement and typing activity and instances of eye-movement activity that occur outside the ST and the TT areas of the screen do not necessarily reflect cognitive disengagement from the translation task. However, since there is no data during these periods to indicate that cognitive resources are invested in language comprehension or language production, they are not included in the analyses.

5.2.3.2 Pupil size calculation

A pupil size score for each AU was identified by calculating the mean of the gaze rows which constituted the AU. As established in section 3.3.1.4, research in pupillometry as a tool to measure cognitive load has shown that the pupils constrict and dilate with some delay relative to the presentation of the stimulus. To account for this delay, or latency, in pupillary movement, pupil size was annotated with a dislocation of 120 ms. For example, in a log file an STAU would begin, for instance, 61,300 ms and end 62,750 ms after a recording had been started. The STAU would thus last 1,450 ms. Having built in a 120 ms delay in the formulas, calculations of the pupil size value was based on the gaze rows that fall within 61,420 ms (61,300 ms + 120 ms) and 62,870 ms (62,750 ms + 120 ms) after the recording had been started. The duration of the AU would obviously still be 1.45 seconds, but the pupil size value would be based on gaze rows that were dislocated by 120 ms relative to the original gaze samples constituting the AU.

The 120 ms delay used in the present study is based on (1) the lower 100 ms estimate, proposed by Beatty (1982) (see also section 3.3.1.4), as the minimum time by which the participants' pupils respond to changes in cognitive load, and (2) heuristic analysis, in which several latency values were tested. In the heuristic analysis, latency values of 100 ms, 120 ms, 200 ms, 300 ms, 400 ms and 500 ms were tested on the data from four randomly selected participants; the 120 ms test was the only one to reveal a systematic pattern. The pattern that was identified showed that pupil size means were systematically different for ST processing, TT processing and parallel processing. In all other tests, there were no noticeable differences between the three types of processing.

Pupillary response latencies most likely varied between the study's 24 participants and probably also within-participant from one AU to another. It was, however, not possible to take into account all the potential between-participant and within-participant differences. A fixed pupillary measuring delay of 120 ms was nevertheless anticipated to capture changes in cognitive load more precisely than if no pupillary measuring delay had been implemented. In future studies, one way to deal with the between-participant differences could be to calculate baseline measurements of pupillary response latency for each participant prior to the actual translation, which could then be built into the formula. However, no immediate solution presents itself to measure differences in pupillary response latencies on an AU-to-AU basis.

5.3 Statistical analysis

Within the field of translation process research, emphasis is often placed on the necessity of collecting process data in a naturalistic setting under the reasonable assumption that naturalistic data provide better correlation with 'real-life' cognitive processing than do data which have been collected in a controlled setting. Statistical analysis of process data have often relied on descriptive statistics, typically using means and percentages, inferential statistics, most often using tests such as ANOVA, or a combination of the two methods. Descriptive analyses and ANOVA are, however, not the best choices of approach when it comes to statistical exploration of data from naturalistic experiments. Descriptive statistics only describe the surface features of a data set by providing summarised figures such as means, and it does not account for the differences between subsets of data. For instance, descriptive comparison of means may show large numerical differences between two subsets of data which are in fact not significantly different from each other when analysed inferentially. In other words, a difference between two means does not necessarily generalise beyond a current sample just because the means are different. With respect to using ANOVAs for naturalistically oriented experiments, it may often be an ill-chosen inferential technique. More specifically, since factorial designs using ANOVAs assume a high degree of experimental control – something which is very difficult if not impossible in a naturalistic setting – this type of inferential technique is not well suited for exploring naturalistic data (Balling 2008a: 176).

The present study applies a factorial design using linear mixed-effects regression (LMER) modelling. As summarised by Balling (2008b: 95), linear mixed-effects modelling appears to be the most powerful statistical method for analysis of data from a design such as the present as it includes both fixed effects and random effects. The models were constructed using the LMER models that are available in the lme4 library (Bates *et al*. 2010) in the statistical programming language R (version 2.11.2010-05-30).[28]

5.3.1 Fixed and random effects

Mixed-effects designs, such as the one used in this study, include both fixed and random effects. Fixed factors are repeatable (each level may recur throughout a data set), and they have a fixed number of levels. The number of levels of a given fixed factor exhausts the number of all potential fixed factor levels that are of interest in a given study (e.g. Balling 2008b: 95). Four fixed factors (i.e. independent variables) are investigated in this

[28] *R* is available from http://www.r-project.org/

study: AttentionType, which has three levels (ST attention, TT attention and parallel ST/TT attention); Group, which has two levels (professional translators and student translators); TextComplexity, which has three levels (TextA, TextB and TextC); and finally, TimeConstraint, which has three levels (TimeConstraintNone, TimeConstraint100 and TimeConstraint85).

Unlike fixed factors, random factors are not repeatable (each level can occur only once), and their levels may be construed as a sample of a large population of levels (e.g. Balling 2008b: 95, Kleinbaum *et al.* 2008: 422). In theory, the number of random factor levels is inexhaustible. In this study, there is one random factor: Participant. The number of random factor levels for Participant in the sampled population is 24 (12 professional translators and 12 student translators).

In Chapter 6, three overall LMER models are used to analyse the relationship between the independent variables (processing type, translational expertise, source text complexity and time constraint) and one of the dependent variables (total attention duration (TA duration), attention unit duration (AU duration) and pupil size). The dependent variables are measurements in seconds, milliseconds and millimetres, respectively.

5.3.2 Data filtering and normalisation

A .csv-data file containing information about AU duration and pupil size (see section 5.2) was imported into R. Once imported, rows that contained no data were removed (i.e. NoDataAUs). No eye movement or typing events, which can be said to involve ST processing, TT processing or parallel ST/TT processing, are registered in the NoData AUs. Information about the participant's focus of attention during instances of NoData is therefore unavailable, and NoDataAUs are therefore removed from the data set. 13.5 percent of all data points were deleted when NoDataAUs were removed. Next, AUs were removed that were shorter than 100 ms in duration as they were assumed not to provide reliable indication of the location of the participant's focus of attention. The 100 ms threshold which was adopted here rested on the minimum fixation duration setting which was identified in section 5.1.3.3 above. A further 4.5 percent of all observations were removed in this way; the specific removal percentages were: STAUs = 7.2 percent, TTAUs = 2.4 percent and PAUs = 6.1 percent.

Use of a linear mixed-effects model assumes that the distribution of residuals (i.e. the *differences* between the data points and the sample mean) in a given data set is normally distributed. A data set is normally distributed when residuals concentrate symmetrically around the mean of the distribution, resembling a bell-shaped curve (Rasinger 2008: 130). Analysis of non-normally distributed data could result in significant effects that are driven by random outliers and not by genuine differences between subsets of data points (Baayen 2009: 92). The distribution of data for two of the three LMER models used in the analyses in Chapter 6 were skewed; in both data sets, distributions were heavily positively skewed, meaning that most data points concentrated around the left of the distribution with a long right tail. To account for the problem of skewness, the data were transformed using a logarithmic function (Baayen 2009: 31). By doing so, the distribution of the study's data points became more symmetrical, and the risk of observing significant effects that were driven by random outliers was reduced dramatically.

5.3.3 Post-hoc analysis

The hypotheses in Chapter 3 were formulated in such a way that they could be partly explained by the main effect of one independent variable, for example AttentionType, on one dependent variable, for example AU duration. In an exploratory study such as the present, the simple hypotheses to do with main effects are intended to motivate further analysis and discussion beyond what follows immediately from the relationship between one dependent and one independent variable. The design discussed above may help some of the way in exploring a hypothesis as it considers the interaction effects of two or more independent variables on one dependent variable; however, a significant main or interaction effect of the LMER analysis would not show if all or only some of the possible comparisons between factor levels are significant. For instance, a significant interaction effect might be observed between AttentionType and Group on AU duration ($p < 0.0001$). Recall that AttentionType consists of three levels (ST attention, TT attention and parallel ST/TT attention) and Group consists of two levels (professional translators and student translators). This means that there are in fact possibly 15 comparisons that may drive the interaction effect, for example one between the duration of professional translators' STAUs and the duration of professional translators' TTAUs. To account for potential differences between pairs of factor level combinations, post-hoc follow-up analysis was used in the present study. In the three overall LMER analyses performed in Chapter 6, post-hoc comparison is necessary more often than not since the LMER model does not specify a priori all potentially relevant comparisons. Also, since most of the fixed factors have more than two levels, it is not possible to identify from the results of the overall LMER analyses which specific contrast(s) are responsible for a significant main or interaction effect. In fact, the only situation in which no post-hoc analysis is needed is when exploring the effect on a dependent variable of Group, which is a two-level factor. Here, the main effect of Group is given in the overall results of the LMER analysis.

The post-hoc comparisons were run by constructing additional LMER models for those subsets of the data that were relevant for the comparisons in question. Descriptive statistics, in the form of bar plots of mean values, were used to illustrate the comparisons that were to be carried out. An LMER model for post-hoc analysis is constructed by defining a reference level, or an anchor point, in which is specified relevant factor level(s). For instance, in the comparison between STAU duration of professional translators and TTAU duration of professional translators (see section 6.2.3), the reference level is defined as [Attention*ST*:Group*P*]. This specific reference level contains two factor levels: level *ST attention* for the factor *AttentionType*, and level *professional translators* for the factor *Group*. It is not necessary to specify the factor level combination [Attention*TT*:Group*P*] that one wishes to compare with the reference level since the LMER model automatically compares the reference level with all factor level combinations into which enters one of the reference level's factor levels. In the example above, the reference level and the factor level combination share factor level [Group*P*]. The post-hoc comparison will return two figures: a t-value and a p-value, e.g. ($t = 15.366$, $p < 0.0001$). The p-value indicates the probability that the null-hypothesis (which is the tentative hypothesis stating that there is no effect) is actually true; the lower the p-value, the more likely is it that the null hypothesis is false and the difference is therefore significant. The t-value is an estimate of the differences in the means between two subsets of data. A positive t-value indicates that the factor level combination is greater than the reference level, and a negative t-value indicates the opposite. In the present study, in which data have been logarithmically transformed, t-values do not necessarily reflect the same trend as illustrated in the descriptive bar plots. It might be that there is a positive difference between the means of two subsets of data, which turns out to be negative when treating the subsets inferentially. The t-value should *always* be considered more reliable than descriptive differences between means, since the logarithmic function reduces the influence of a few outlier data points (Baayen 2009: 31).

Multiple post-hoc comparisons were carried out for each of the three LMER analyses. Performing multiple comparisons simultaneously comes at the cost of increasing the probability of a Type I error, or a false positive (Rasinger 2008: 160-161). That is, the risk increases that a significant difference is postulated when in fact there is none. In order to address this problem, Bonferroni corrections were used in all analyses. Instead of using the standard 0.05 p-level for significance, a lower p-level was used. The Bonferroni corrected p-level was arrived at by dividing the standard 0.05 p-level by the number of post-hoc comparisons (n) that were to be carried out. So, for instance, if $n = 8$

comparisons were to be carried out, the new p-level would be 0.05 / 8 = 0.006 (Baayen 2009: 105). Bonferroni correction is a conservative adjustment in that it increases the probability of a Type II error, or a false negative, which means that the risk increases of postulating non-significant differences that are in fact significant. Bonferroni correction was nevertheless still preferred over no correction since (1) a high number of post-hoc comparisons were carried out in the study's analyses and (2) Type I errors are more problematic than Type II errors; more specifically, not postulating a significant effect when there in fact was one was preferred over postulating a significant effect when there in fact was none. Bonferroni corrections were carried out in each of the three analyses in sections 6.1, 6.2 and 6.3.

Chapter 6

Results and discussion

This chapter examines the study's three research questions by examining the 15 hypotheses presented in section 3.4.2. As emphasised (ibid.), the study's hypotheses constitute points of departures for further analysis and discussion as interactions between one dependent variable and multiple independent variables will be considered in order to examine how the study's other factors affect the validity of a given hypothesis.

Different terms are used in different settings to refer to a factor, cf. Table 6. The general reference to a factor/independent variable is listed in the left column; the name of this factor used in the LMER models (see section 5.3) is listed in the middle column; and the shortened name used in the post-hoc analyses (see section 5.3.3) is listed in the right column.

Table 6: Factor terminology

Factor / independent variable	***LMER***	***Post-hoc shortening***
Processing type	AttentionType	Attention
Translational expertise	Group	Group
Source text difficulty	TextComplexity	Text
Time pressure	TimeConstraint	Time

In the following, each hypothesis will be considered in separate sections. As an example, the analysis of hypothesis H5a in section 6.2.3 first considers the main effect of AttentionType. Next, it considers significant interactions into which AttentionType entered. Four interactions are therefore considered: (1) AttentionType and Group, (2) AttentionType, Group and TimeConstraint, (3) AttentionType and TimeConstraint and (4) AttentionType, TimeConstraint and TextComplexity. For each main and interaction effect, statistical findings are presented and discussed, and a summary and conclusions are presented at the end of the section.

Since an interaction consists of at least two factors (e.g. AttentionType and Group), the same significant interaction will be considered for several hypotheses. As an example, the interaction between AttentionType and Group is considered also in relation to hypothesis H6 in section 6.2.4. Here, it will be labelled Group and AttentionType to indicate that the analyses and discussions focus on Group differences rather than AttentionType differences.

6.1 Distribution of cognitive resources

This section will report on the analyses carried out to examine the five single-factor hypotheses, to do with distribution of cognitive resources, which were formulated in relation to research question **R1**. The research question asked: "What is the distribution of cognitive resources during translation?" The present analysis treated all AUs of the same type as one single aggregate (TA) unit. This means that the analysis was limited to 216 data points (24 translators x 3 texts x 3 types of AUs = 216). Calculations of means, linear mixed-effects modelling and post-hoc analysis were used in the investigation.

In section 6.1.1, the statistical model that was fitted for the analysis of TA duration is presented with main and interaction effects. Sections 6.1.2 to 6.1.5 discuss the hypotheses. Section 6.1.6 presents a conclusion.

6.1.1 Statistical methods and effects

An LMER model (see section 5.3) was used to analyse the 24 participants' distribution of cognitive resources. The model related the dependent variable *TA duration* to the four independent variables AttentionType, Group, TextComplexity and TimeConstraint. The dependent variable TA duration was logarithmically transformed to reduce skewness. Prior to the logarithmic transformation, the distribution of data was positively skewed.[29] Post-transformation, the distribution was still skewed (negatively), but not as alarmingly as prior logarithmic transformation, since the data concentrated more around the middle, cf. Figure 6.1a:

[29] A positively skewed distribution means that the mass of the distribution is concentrated to the left of the figure, having a longer right tail; a negatively skewed distribution means that the mass of the distribution is concentrated to the right of the figure, having a longer left tail (see also section 5.3.2).

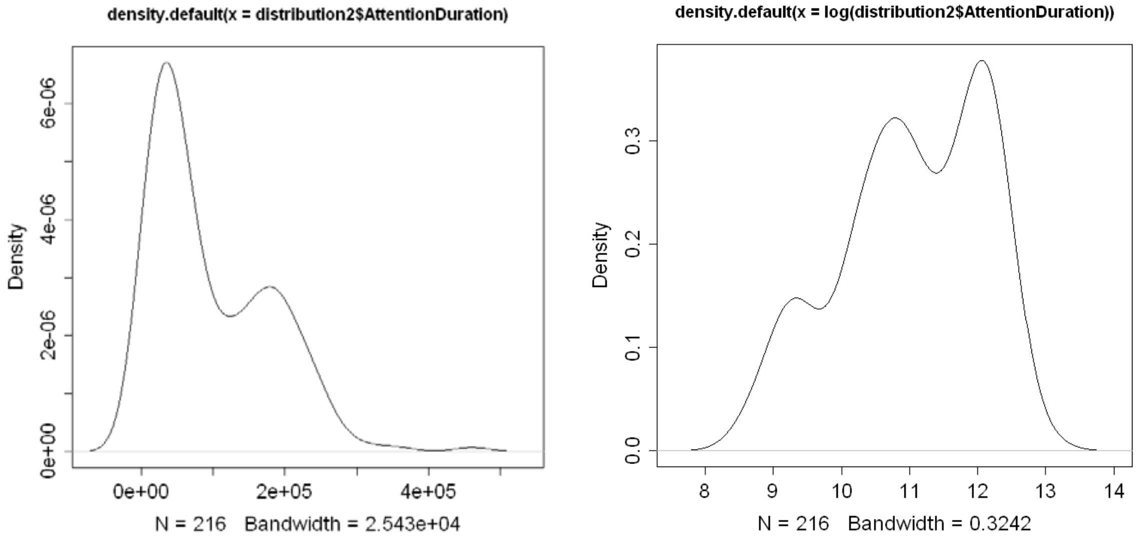

Figure 6.1a: Data distribution before and after logarithmic transformation (TA duration)

After the data set had been logarithmically transformed, an LMER model was constructed, in which non-significant variables were removed in a stepwise backward manner as suggested by Balling (2008b: 99 and 154). Removal of non-significant variables in this manner makes the interpretation of the model much easier, and, more importantly, there is a lower risk that significant effects are obscured by the inclusion of non-significant effects (ibid. 99). The procedure was as follows: first, an initial model was fitted, which included all possible main and interaction effects between the four independent variables. Next, interactions that were non-significant were removed. The final model included only two fixed factors (AttentionType and Group) in addition to the random factor Participant.

Table 6.1a presents the significant main and interaction effects of the reduced LMER model. The column *Sig.* provides an interpretation of the significance level for each effect; one asterisk (*) indicates that the effect was significant at or just below the 0.05 level, two asterisks (**) indicate that the effect was highly significant ($p < 0.01$) while three asterisks (***) indicate that the effect was very highly significant ($p < 0.0001$):

Table 6.1a: Significant main effect and interaction effect of TA duration

Effect (TA duration)	*Df*	*Sum sq*	*Mean sq*	*F value*	*p(t)*	*Sig.*
AttentionType	2	161.934	80.967	274.9618	< 0.0001	***
Group	1	0.025	0.025	0.0846	0.8	
AttentionType:Group	2	11.155	5.577	18.9410	< 0.0001	***

Df2 for all effects was 210

The LMER analysis showed a very highly significant main effect of AttentionType and a very highly significant interaction effect between Group and AttentionType. No other effects reached significance.

For the post-hoc analysis, the significance level (see section 5.3.3 above) was adjusted by dividing the standard 0.05 p-level by the total number of post-hoc comparisons that were to be carried out (n = 12). Doing so, the new p-level for the post-hoc comparisons (not to be confused with the LMER model p-level, which remained 0.05) was 0.004. Any effect of a post-hoc comparison that had a p-value of more than 0.004 was considered non-significant.

6.1.2 TA duration and AttentionType

This section will examine the two hypotheses to do with distribution of cognitive resources and processing type. Hypothesis **H1a** predicted that translators spend more time on TT processing than on ST processing, and hypothesis **H1b** predicted that translators spend less time on parallel ST/TT processing than on ST processing and TT processing.

The very highly significant main effect of AttentionType ($F = 274.9618$, $p < 0.0001$) indicated that there were differences in the amount of time spent on ST processing, TT processing and parallel ST/TT processing; the descriptive figures presented in Figure 6.1b below offer some support: the mean amount of time allocated to the TT was 194.9 seconds of the total translation (66.3 percent). ST attention accounted for approximately a third of that, namely 70.9 seconds (24.1 percent). Finally, parallel ST/TT attention constituted some 28.1 seconds of the total translation time (9.6 percent).

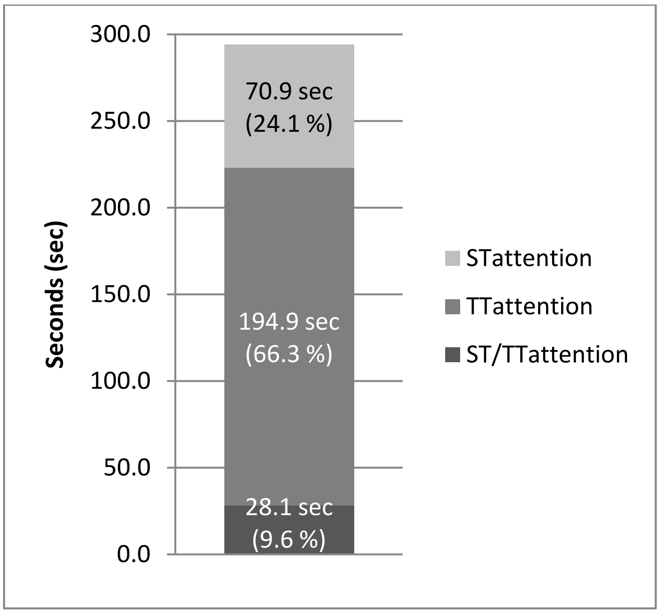

Figure 6.1b: Distribution of attention: AttentionType

Since the main effect only indicated an overall effect of AttentionType and since generalisation beyond the present sample cannot be made from the descriptive figures, post-hoc comparisons were performed to investigate if differences between the relevant pairs were significant.

To test hypothesis **H1a**, a post-hoc comparison between [Attention*ST*] and [Attention*TT*] was carried out. The comparison showed a significant difference between the amount of time allocated to ST processing and the amount of time allocated to TT processing ($t = 19.781$, $p < 0.0001$) as most time was allocated to TT processing. Based on this analysis, the hypothesis is confirmed, and it is concluded that translators generally engage more in TT processing than they do in ST processing.

With respect to hypothesis **H1b,** two post-hoc comparisons were performed between [Attention*Parallel*] and [Attention*ST*] and between [Attention*Parallel*] and [Attention*TT*]. The results from these two comparisons also revealed significant differences ($t = 6.838$, $p < 0.0001$ and $t = 26.619$, $p < 0.0001$) in that the amount of time allocated to parallel ST/TT processing was significantly less than that allocated to ST processing and to TT processing separately. This hypothesis is therefore also confirmed as the findings indicate that parallel processing occurs in translation in addition to sequential processing (see section 3.2.4).

AttentionType entered into a significant interaction with Group. The validity of the two hypotheses may therefore be affected when considering the relationship between *AttentionType and Group*.

Distribution of attention: AttentionType and Group

The interaction between AttentionType and Group was very highly significant ($F = 18.9410$, $p < 0.0001$), which suggested that the time spent on ST processing, TT processing and on parallel ST/TT processing was different for professional translators and for student translators.

The means in Figure 6.1c below reveal that both professional translators and student translators allocated considerably more time to TT processing compared to that allocated to ST processing and to parallel ST/TT processing. For professional translators, mean TT processing time was 187.2 seconds, mean ST processing time was 54.7 seconds and mean parallel ST/TT processing time was 33.4 seconds. For student translators, mean TT processing time was 202.6 seconds, mean ST processing time was 87.1 seconds and mean parallel ST/TT processing time was 22.8 seconds. The means illustrate the same trend as those indicated by the means in Figure 6.1c above, namely that most time was spent on TT processing and least time was spent on parallel ST/TT processing.

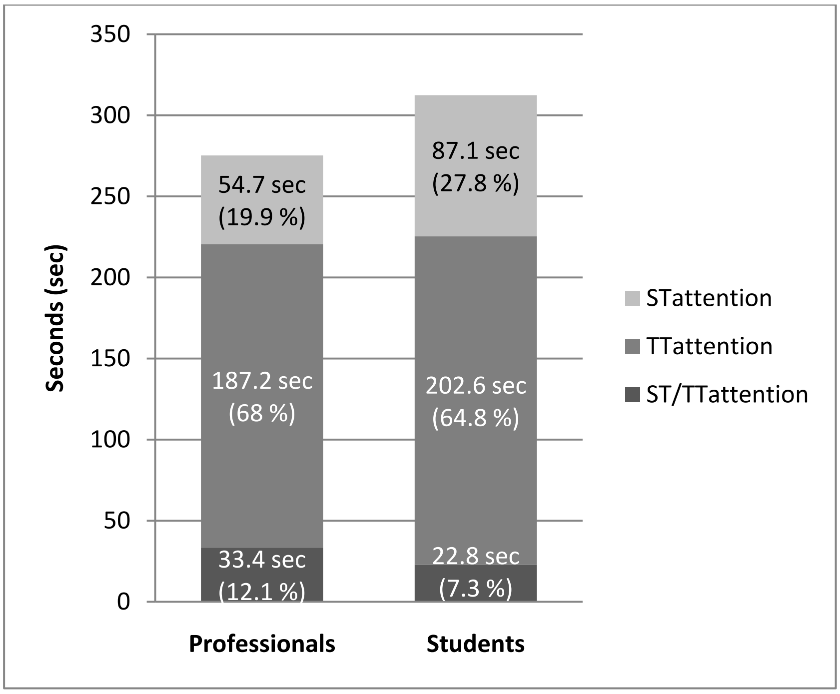

Figure 6.1c: Distribution of attention: AttentionType and Group

In order to test if there were significant within-group differences, six post-hoc comparisons were conducted. The three comparisons for professional translators were: [Attention*ST*:Group*P*] and [Attention*TT*:Group*P*] ($t = 15.366$, $p < 0.0001$); [Attention*ST*:Group*P*] and [Attention*Parallel*:Group*P*] ($t = -2.473$, $p = 0.0142$); and [Attention*TT*:Group*P*] and

[Attention*Parallel*:Group*P*] ($t = -17.840$, $p < 0.0001$). The three comparisons for student translators were: [Attention*ST*:Group*S*] and [Attention*TT*:Group*S*] ($t = 13.380$, $p < 0.0001$); [Attention*ST*:Group*S*] and [Attention*Parallel*:Group*S*] ($t = -7.464$, $p < 0.0001$); and [Attention*TT*:Group*S*] and [Attention*Parallel*:Group*S*] ($t = -20.844$, $p < 0.0001$).

The three comparisons for the professional translators showed that this group allocated significantly more time to TT processing than to both ST processing and parallel ST/TT processing. There was, however, no significant difference between ST processing and parallel ST/TT processing at the Bonferroni corrected p-level of 0.004. The three comparisons for the student translators showed that they also allocated significantly more time to TT processing than to both ST processing and to parallel ST/TT processing. Unlike the professional translators, the student translators did in fact spend significantly more time on ST processing than on parallel ST/TT processing.

With respect to hypothesis **H1a**, this is still confirmed as both professional translators and student translators spent more time on TT processing than on ST processing. Following these observations, both professional translators and student translators allocate more cognitive resources to TT processing than to ST processing. Hypothesis **H1b** is only confirmed for student translators, who spent more time on both ST processing and TT processing than on parallel ST/TT processing; professional translators only spent more time on TT processing than on parallel ST/TT processing while the comparison between ST processing and parallel ST/TT processing was non-significant. One reason why the post-hoc comparisons could not confirm this hypothesis for professional translators, in spite of the large difference in the means, could be that there is too little data on which to perform the comparisons. This possible explanation is considered in more detail below.

Summary and discussion (hypothesis H1a)

In this section, hypothesis, **H1a** was considered. The hypothesis stated that “translators spend more time on TT processing than on ST processing”. Table 6.1b below summarises the findings from the analyses that were carried out.

Table 6.1b: Status of hypothesis H1a

Factor(s) / Status	Attention	Attention:Group
Confirmation	✓ Translators spent more time on TT processing than on ST processing.	✓ Both groups spent more time on TT processing than on ST processing.
Modifier	*(none)*	*(none)*

Based on the analysis above, hypothesis **H1a** is confirmed as all relevant post-hoc comparisons to do with the significant main effect and interaction effect were significant. Translators, considered as one group and as two separate groups of professional translators and student translators, spent more time and thus more cognitive resources on TT processing than on ST processing. These findings agree well with earlier findings from translation process studies which have indicated that TT processing is generally more time consuming than ST processing; for instance, Jääskeläinen (1999) (see also section 2.2.1) found that translators verbalise TT processing more than they verbalise ST comprehension. The findings from Jakobsen and Jensen's (2008) eye-tracking study also indicated more time spent on TT processing than on ST processing.

Considering the subprocesses involved in ST processing and TT processing, which were outlined in sections 3.2.1 and 3.2.2, ST reading and ST comprehension are far less time consuming than TT reading, TT reformulation and TT typing. This analysis of cognitive resource distribution does not differentiate between the subtypes of ST processing and TT processing, and although it may be that low cognitively demanding TT typing causes the considerable difference between ST processing and TT processing, it is here argued that it is TT reformulation, which causes the considerable difference between ST processing and TT processing. This proposal is supported by the claim by Eysenck and Keane (2005: 419), who note that the processes involved in language production demand more WM resources than most comprehension tasks. On this basis, it is concluded that more cognitive resources are involved in TT reformulation than in ST comprehension during translation.

AttentionType did not enter into significant interactions with TextComplexity or TimeConstraint. Based on the present analysis, it would appear that source text difficulty and time pressure do not affect the amount of time allocated to ST processing, TT processing or to parallel ST/TT processing.

Summary and discussion (hypothesis H1b)

Hypothesis **H1b** stated that "translators spend less time on parallel ST/TT processing than on ST processing and TT processing". Table 6.1c below summarises the findings from the analyses that were carried out to examine this hypothesis.

Table 6.1c: Status of hypothesis H1b

Factor(s) / Status	Attention	Attention:Group
Confirmation	✓ Translators spent less time on parallel ST/TT processing than on ST processing and on TT processing.	✓ Students spent less time on parallel ST/TT processing than on ST processing and on TT processing. ✓ Professionals spent less time on parallel ST/TT processing than on TT processing.
Modifier	*(none)*	- (*Professionals did not spend significantly less time on parallel ST/TT processing than on ST processing.*)

The observations provide some support for the *parallel* view (see section 3.2.4.2) of the translation process as there is evidence that ST processing and TT processing were performed simultaneously. There is, however, also support to be found for the *sequential* view (see section 3.2.4.1) of the translation process as the data indicated that ST processing and TT processing, in fact for the most part, were performed separately. Considered as one homogenous group, translators engage in more separate ST processing and more separate TT processing than in parallel ST/TT processing. However, when considering each group separately, the hypothesis is confirmed for student translators only and not for professional translators; hypothesis H1b is therefore partially confirmed.

Since it cannot be ruled out that parallel ST/TT processing takes place during instances of ST processing or TT processing (see sections 3.3.1.3 and 3.3.3), the study's results with respect to the *proportions* of parallel processing and sequential processing in translation should be considered provisional. It is not possible to infer from the data the extent to which the translator engages in parallel ST/TT processing without typing. However, the present analysis establishes that *manifested* parallel processing, as indicated by co-occurring TT typing and ST reading, occurs in translation in addition to *manifested* sequential processing, and the distribution of cognitive resources to parallel ST/TT processing is conditioned by the translator's ability to touch type.

One explanation for the lack of significance with respect to the professional translators might be that the analysis rests on too little data. Overall, the data set used to calculate TA duration consists of 216 data points; for the present purpose, 216 data points is a very small sample size and it may often be problematic to make generalisations from such a small amount of data. This issue will be dealt with below as the problem of lack of significance persists with the other analyses of section 6.1.

6.1.3 TA duration and Group

Hypothesis **H2** is examined in the following section. The hypothesis stated that "student translators spend more time on a translation task than professional translators". The means reveal that the professional translators finished their translations in 275.3 seconds while the student translators finished their translations in 312.5 seconds. Although the means indicate differences between the two groups, the main effect of Group on TA duration did not reach significance ($F = 0.0846$, $p = 0.8$), and the hypothesis therefore cannot be confirmed. However, since Group entered into a very highly significant interaction with AttentionType ($F = 18.9410$, $p < 0.0001$), the hypothesis may well be confirmed when Group and AttentionType are considered together. The relevant means indicated that there were between-group differences: ST processing duration was 54.7 seconds for professional translators and 87.1 seconds for student translators. TT processing duration was 187.4 seconds for professional translators and 202.6 seconds for student translators, and finally parallel ST/TT processing duration was 33.4 seconds for professional translators and 22.8 seconds for student translators.

In order to test if the differences indicated by the means were significant, three post-hoc comparisons were carried out. The comparisons were: [Attention*ST*:Group*P*] and [Attention*ST*:Group*S*] ($t = 2.682$, $p = 0.0079$); [Attention*TT*:Group*P*] and [Attention*TT*:Group*S*] ($t = 1.266$, $p = 0.2$); and [Attention*Parallel*:Group*P*] and [Attention*Parallel*:Group*S*] ($t = -0.876$, $p = 0.4$). As illustrated by the p-values, none of the three comparisons reached significance. The post-hoc comparisons were not able to provide support for hypothesis H2, in spite of the differences between professional translators and student translators suggested by the means. The very highly significant effect of the Group and AttentionType interaction seems to be driven by the within-group differences, reported in section 6.1.2 above, rather than the between-group differences reported here.

One initial explanation why there was no statistical support for the hypothesis could be that professional translators and student translators generally spend the same amount of time on ST processing, TT processing and parallel ST/TT processing. Ignoring the large descriptive differences in the means presented above, this might be a reasonable explanation were it not for the confirmation of hypotheses H6 and H10 discussed later in this chapter. The inferential analyses carried out to examine these two hypotheses found substantial differences between professional translators and student translators. On this basis, it is considered improbable that professional translators and student translators spend the same amount of time on translation.

Another explanation why this study was not able to identify significant differences in support of hypothesis H2 is that the data set TA duration is too small. This concern has already been raised above. Each of the three post-hoc comparisons performed here compared only 36 data points from the professional translators (one data point per text x 3 texts per translator x 12 professional translators) with 36 data points from the student translators. It is possible that significant differences would have been registered if more data and thus more data points had been available.

6.1.4 TA duration and TextComplexity

This section will examine hypothesis **H3**, which predicted that “the translation of a difficult source text requires more time than the translation of an easy source text”. The relevant means indicate that there is a relationship between text difficulty and time spent on translation: 268.2 seconds were spent on translating the less complex TextA, 303.2 seconds were spent translating the moderately complex TextB, and 310.2 seconds were spent translating the more complex TextC. The LMER model did not, however, show any significant main or interaction effects into which entered TextComplexity, and the hypothesis cannot be confirmed.

A provisional explanation is that the translators did not experience any difference between the experimental texts with respect to their levels of difficulty. Although the texts were made to differ with respect to their levels of complexity, it may very well be that the mechanical indicators of complexity that were used in the design of the experimental texts are unsuitable as predictors of translation difficulty. More specifically, complexity measurements of readability, word frequency and non-literalness do not reflect the amount of processing effort which is likely to be invested in the translation of a given text. Another explanation is that more complex source texts, although experienced as being more difficult (i.e. involving higher cognitive load), generally do not require more time to be translated than less complex source texts. The plausibility of this explanation relies on confirmation of hypothesis H11, which uses pupil size to reflect an increase in cognitive load (see section 6.3.4). Hypothesis H11 was not confirmed, and this explanation therefore seems unlikely. A third explanation, which was also suggested in sections 6.1.2 and 6.1.3 above, is that the analysis of TA duration is based on too little data. Significant differences might well have been observed if the analysis had rested on more data. As with the previous analyses, the present one in relation to hypothesis H3 rests on 216 data points.

6.1.5 TA duration and TimeConstraint

In the following section, hypothesis **H4** is examined. The hypothesis stated that “translation under time pressure is performed more quickly than translation under no time pressure”. The overall means provide some tentative support for this intuitively obvious hypothesis as there was a decrease in the amount of time spent on translation when carried out under time pressure. More specifically, translators spent 335.2 seconds translating texts under no time constraint, 292.6 seconds translating texts under the moderate time constraint (TimeConstraint 100), and 253.9 seconds translating texts under the heavy time constraint (TimeConstraint 85). However, the LMER model was not able to support the differences in the means, and the hypothesis could not be confirmed.

It is surprising that the intuitively obvious hypothesis, predicting that time pressure affects the amount of time spent on translation, could not be confirmed. An explanation is that the study’s participants did not experience considerable time pressure by the time constraints that were imposed during the translation of two of the three texts. The flexible time constraints were calculated on the bases of individual warm-up task times for each translator, and it was anticipated that the use of flexible time constraints, instead of *fixed* time constraints, would cause experiences of time pressure on the part of all translators (see section 4.4). According to this analysis, it seemed not to be the case that the translators experienced time pressure, possibly because the flexible time constraint values were not sufficiently restrictive. However, this explanation seems unlikely, in part because there *is* an intuitive relationship between time consumption and time pressure, but also because the analyses of management of cognitive resources (see section 6.2.6) and cognitive load (see section 6.3.5) in relation to time pressure found significant differences between texts translated under time constraint and under no time constraint. A second explanation, which has also been mentioned above, is that the present analysis is based on too little data. This explanation seems more appealing since the very low number of significant effects (only two) of the overall LMER analysis conducted here in section 6.1 compared with the high number of significant effects found in the LMER analyses conducted in sections 6.2 and 6.3 indicate that there is too little data on which to perform inferential analysis.

6.1.6 Conclusion on distribution of cognitive resources

The first research question asked: *What is the distribution of cognitive resources during translation?* Five hypotheses were tested to investigate this research question. Hypothesis **H1a** was confirmed, while hypothesis **H1b** was partially confirmed. The remaining three hypotheses **H2**, **H3**, and **H4** were not confirmed.

With respect to hypothesis **H1a**, the analyses showed that both professional translators and student translators spent more time on TT processing than on ST processing. With respect to hypothesis **H1b**, it was found that translators engaged in more TT processing than in parallel ST/TT processing; translators did not, however, engage in significantly more ST processing than in parallel ST/TT processing. For both hypotheses, no other interactions were significant, and the distribution of cognitive resources during translation is apparently not different when considering source text complexity and time pressure.

Several explanations were proposed for the lack of confirmation for hypotheses **H2**, **H3** and **H4**. It was speculated that differences in translational expertise, differences in source text difficulty and time pressure simply do not affect the distribution of cognitive resources during translation, regardless of the number of translators from which process data are obtained. This explanation stands in contrast, however, to many of the findings of the analyses in sections 6.2 and 6.3, which were significant. Another more likely explanation was that the TA duration data set is too small. More specifically, there are only a total of 216 data points on which to calculate main effects. This is a fairly low number, especially if the study also wishes to analyse interaction effects. The lower the number of data points available, the higher is the risk of observing Type II errors, or false negatives (see section 5.3). In other words, given the low number of data points, the LMER model may report non-significant p-values that would have turned out to be significant had the data set been sufficiently large. The problem becomes even more serious when considering interaction effects. For instance, when calculating the interaction effect of AttentionType and Group on TA Duration, the LMER model is restricted to 36 data points for each level (e.g. the Group level *professional translators* combined with the AttentionType level *ST attention* only has 36 data points). Three-way and four-way interactions compromise the reliability of the findings further, as the number of data points for each factor level combination is even lower; for instance, the number of data points for each level of a three-way interaction between AttentionType, Group and TimeConstraint is only 12, and in a four-way interaction there are only four data points available for each factor level combination. In comparison, the analyses of sections 6.2 and 6.3 base their findings on around 23,000 and 18,000 data points, respectively, which are considerably more than the 216 data points in the present analysis. It should be noted that the small data set does not invalidate the findings which support the confirmation of hypotheses H1a and H1b. These hypotheses are considered confirmed, also in the light of the problem with the low number of data points. The differences between the data points in those subsets of data were most likely large enough to be captured by the LMER model and the post-hoc comparisons.

Overall, the TA duration indicator was only partially successful in reflecting translators' distribution of cognitive resources during translation. Since the TA duration indicator suffers under the general problem of scarcity of data, other and more powerful alternatives in terms of statistical validity, such as the AU duration and pupil size indicators, were employed to investigate the allocation of cognitive resources in translation.

6.2 Management of cognitive resources

The study's second research question **R2** asked "How are cognitive resources managed during translation*?*" To answer this question, five single-factor hypotheses were formulated. Calculations of means, linear mixed-effects modelling and post-hoc analysis were used to test the hypotheses.

Section 6.2.1 presents and discusses the *number* of AUs in the AU duration data set in order to motivate an analysis of AU duration rather than of AU count. In section 6.2.2, the results from the statistical model are introduced along with an explanation of the LMER model that was fitted for the specific analysis of AU duration. Sections 6.2.3 to 6.2.6 discuss the five hypotheses to do with management of cognitive resources by considering relevant significant main and interaction effects and relevant post-hoc comparisons. Section 6.2.7 deals exclusively with PAU duration, and finally, in section 6.2.8, a conclusion is presented.

6.2.1 Number of attention units

Table 6.2a below lists the total number of AUs for each of the four factors grouped by levels. The mean numbers of AUs per translation are given in parentheses. There were a total of 22,947 AUs in the 72 translations by the 24 translators. The mean number of AUs per translation was thus 319.

Table 6.2a: Number of AUs arranged by independent variable and level. Mean number of AUs per translation are shown in parentheses

AttentionType	**STAUs**	**TTAUs**	**PAUs**
	6,002 (83)	12,282 (171)	4,663 (65)
Group	**Professionals**	**Students**	
	10,857 (301)	12,090 (336)	
TextComplexity	**TextA**	**TextB**	**TextC**
	7,150 (298)	7,826 (326)	7,971 (332)
TimeConstraint	**TimeConstraintNone**	**TimeConstraint100**	**TimeConstraint85**
	8,414 (351)	7,553 (315)	6,980 (291)

Table 6.2a shows that the number of TTAUs was more than double that of STAUs. The table also shows that the number of PAUs was lower than both STAU and TTAU. Around 11 percent more AUs were identified in the student translators' translations than in the

professional translators' translations. The number of AUs sorted by TextComplexity and TimeConstraint indicated progression, as the heaviest time constraint (TimeConstraint85) resulted in fewer AUs than no time constraint and TimeConstraint100. With respect to source text complexity, the most complex text resulted in the highest number of AUs, while the least complex text resulted in the lowest number of AUs.

The numbers above suggest that AUs are flexible entities that are sensitive to the factors investigated in this study (processing type, translational expertise, source text difficulty and time pressure) as the *number* of AUs in a translation changes under different conditions. The differences in AU count provide some tentative support for the five hypotheses; however, statistical analysis of the *number* of AUs would involve the same low number of data points as the analysis reported in section 6.1 above, and hence run a risk of providing no clear-cut hypothesis confirmation. In order to examine the hypotheses more thoroughly, analysis of the *duration* of the AUs was preferred. An analysis of AU duration would be based on around 23,000 data points instead of only 216 in the analysis of AU count. Another equally important argument for analysing AU duration rather than AU count in relation to the translator's management of cognitive resources has to do with the assumption that AU duration reflects the translator's ability to optimise the allocation of cognitive resources. As noted in section 3.4, AU duration is considered an indicator of the translator's conscious response to the processing requirements of the translation task. AU count only indicates *how many* instances of a particular type of processing occur and not for *how long* an instance lasts. Since AU duration provides this information, this variable is considered more suitable in the analysis of translators' management of cognitive resources.

6.2.2 Statistical methods and effects

An LMER model (see section 5.3 above) was constructed in order to analyse the duration of AUs. In addition to *AU duration* as the dependent variable, the model included four independent variables, (AttentionType, Group, TextComplexity and TimeConstraint), and the random factor (Participant). There were 22,947 data points in the AU duration data set.

Logarithmic transformation of the dependent variable AU duration was performed to reduce skewness (see section 5.3.2). Prior to the logarithmic transformation, the distribution was heavily positively skewed. Post-transformation, the distribution remained somewhat positively skewed, but to a much lesser degree, as more data were now located around the middle (Figure 6.2a).

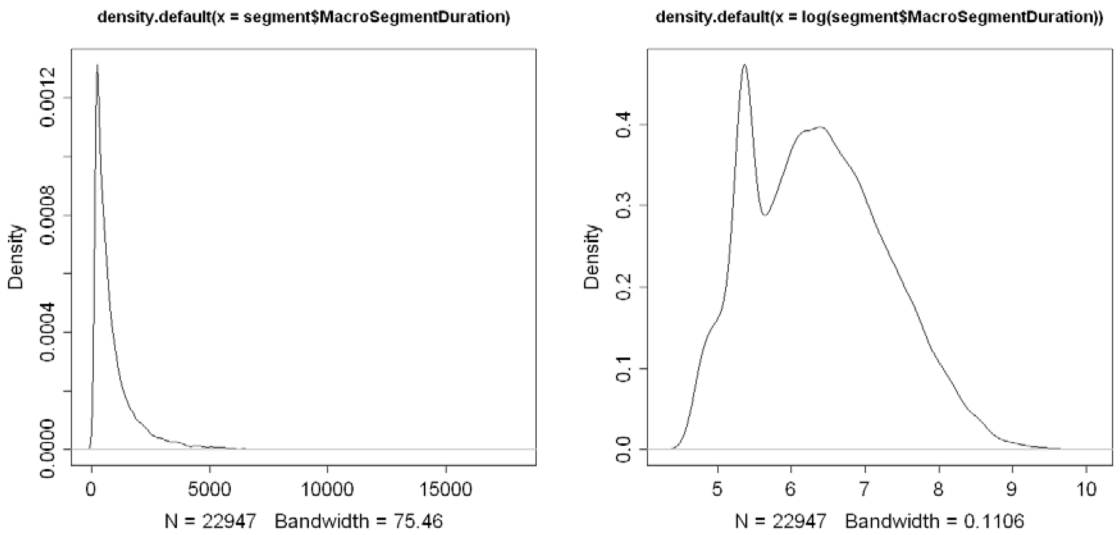

Figure 6.2a: Data distribution before and after logarithmic transformation (AU duration)

Table 6.2b below presents significant as well as non-significant effects of the LMER analysis of AU duration. As in the analysis of distribution of cognitive resources, column *Sig.* (level of significance) offers an interpretation of the significance level for each effect; one asterisk (*) indicates a significant effect at or just below the 0.05 level, two asterisks (**) indicate that the effect was highly significant ($p < 0.01$) and three asterisks (***) indicate that the effect was very highly significant ($p < 0.0001$):

Table 6.2b: Main effects and interaction effects of AU duration

Effect (AU duration)	*Df*	*Sumsq*	*Mean sq*	*F value*	*p(t)*	*Sig*
AttentionType	2	2167.8	1083.9	1542.185	<0.0001	***
Group	1	0.8	0.8	1.1748	0.3	
TextComplexity	2	3.1	1.5	2.1716	0.1	
TimeConstraint	2	19.6	9.8	13.9757	<0.0001	***
AttentionType:Group	2	282.9	141.4	201.2248	<0.0001	***
AttentionType:TextComplexity	4	3.7	0.9	1.3277	0.3	
AttentionType:TimeConstraint	4	25.3	6.3	8.9834	<0.0001	***
Group:TextComplexity	2	1.4	0.7	1.0162	0.4	
Group:TimeConstraint	2	4.5	2.2	3.1865	0.0413	*
TextComplexity:TimeConstraint	4	1.3	0.3	0.4629	0.8	
AttentionType:Group:TextComplexity	4	1.3	0.3	0.4641	0.8	
AttentionType:Group:TimeConstraint	4	6.7	1.7	2.3785	0.0495	*
AttentionType:TextComplexity:TimeConstraint	8	26.7	3.3	4.7451	<0.0001	***
Group:TextComplexity:TimeConstraint	4	13.2	3.3	4.6814	0.0009	**
AttentionType:Group:TextComplexity:TimeConstraint	8	215.5	26.9	38.3250	<0.0001	***

Df2 for all effects was 22964

The LMER model showed very highly significant main effects of TimeConstraint and AttentionType. There were no significant main effects of Group or TextComplexity, but both factors entered into significant interactions. There were significant effects in seven of 11 interactions. Below, each significant main and interaction effect is discussed in relation to the hypotheses to do with AU duration. This means that the same significant interaction effect will be discussed in relation to two or more hypotheses. For instance, the two-way interaction between Group and TimeConstraint will be discussed in relation to hypothesis H6 (to do with translational expertise) as well as in relation to hypothesis H8 (to do with time pressure).

For the post-hoc analysis, the significance level was Bonferroni corrected (see section 5.3.3 above) by dividing the standard 0.05 p-level by the total number of post-hoc comparisons that were carried out (n = 45). Having done so, the new p-level was 0.0011. Any effect in the post-hoc comparisons with a p-value above 0.0011 was considered non-significant. This corrected p-level should not to be confused with the LMER model p-level, which remained 0.05.

The present analysis of AU duration did not compare TextB and TimeConstraint100 with other factor levels. The reason for not including these two factor levels was that even more post-hoc comparisons would have to be performed; the

Bonferroni corrected p-level would then have had to have be even lower, which would have increased the risk of Type II errors. It was not anticipated that the exclusion of these two factor levels would affect the interpretability of the results. Post-hoc comparisons were still carried out between the two other levels of factors TextComplexity and TimeConstraint (i.e. TextA and TextC; and TimeConstraintNone and TimeConstraint85, respectively), which were expected to show stronger effects in a given analysis as these pairs were assumed to represent the extremities on the scales of source text difficulty and time pressure, respectively.

With reference to the problem of the increased risk of Type II errors, post-hoc comparisons in relation to the significant four-way interaction (e.g. between [AttentionTT:GroupS:TextA:TimeNone] and [AttentionTT:GroupP:TextA:TimeNone]) were not performed as the number of comparisons would increase dramatically.

6.2.3 AU duration and AttentionType

This section examines the two hypotheses to do with management of cognitive resources and processing type. The first hypothesis **H5a** stated that TTAUs are of longer duration than STAUs, and the second hypothesis **H5b** stated that translators' PAUs are of shorter duration than STAUs and TTAUs. The main effect of AttentionType on AU duration was very highly significant ($F = 1542.1854$, $p < 0.0001$). As illustrated in Figure 6.2b below, mean STAU duration was 846 ms, mean TTAU duration was 1141 ms while mean PAU duration was 429 ms. Considering the means and the significant main effect, there is some support for both hypotheses. Post-hoc comparisons were carried out to test if differences between the types of processing were significant.

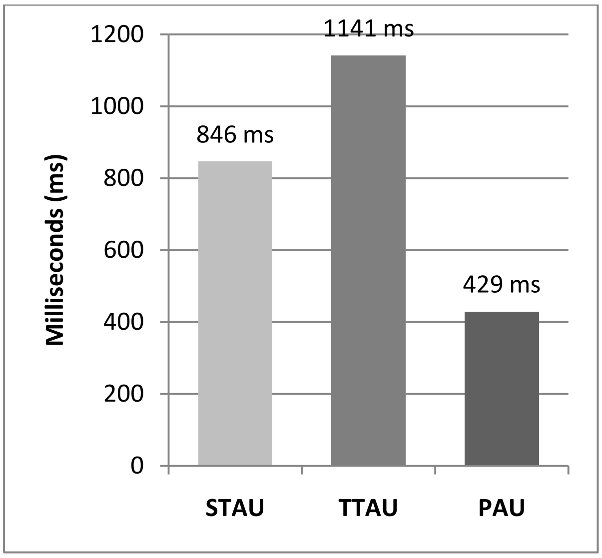

Figure 6.2b: AU duration: AttentionType

First, a post-hoc comparison was carried out between [Attention*ST*] and [Attention*TT*] to test hypothesis **H5a**. The result of the comparison revealed that TTAUs were significantly longer than STAUs ($t = 28.91$, $p < 0.0001$). The very large difference between STAU duration and TTAU duration, as illustrated by the large t-value, shows that translators allocate cognitive resources to ST comprehension for much briefer periods of time compared to TT reformulation; in other words, ST comprehension is performed more quickly than TT reformulation. The reason for this could be that lexical and propositional analyses of ST comprehension are performed relatively more quickly than planning and encoding during TT reformulation (see section 3.2). Attention and thus cognitive resources do not need to be allocated to ST comprehension for as long as resources need to be allocated to TT reformulation. This interpretation is supported by the claim presented by Eysenck and Keane (2005: 419) (also presented in section 6.1.2) that ST processing is less cognitively demanding than TT processing. The hypothesis is so far considered confirmed.

In order to test hypothesis **H5b**, two post-hoc comparisons were carried out between [Attention*Parallel*] and [Attention*TT*] and between [Attention*Parallel*] and [Attention*ST*]. The comparisons show that PAUs were significantly shorter than both TTAUs and STAUs ($t = -53.37$, $p < 0.0001$ and $t = -24.83$, $p < 0.0001$). This hypothesis also appears to have been confirmed. Mean PAU duration was in fact considerably shorter than TTAU and STAU durations. The large differences in the descriptive means between PAU duration and STAU and TTAU duration are supported by very large negative t-values. In addition, the PAU means presented throughout this section show that the duration of PAUs was considerably shorter than those of STAUs and TTAUs duration under all conditions. For these reasons, PAU duration will not be considered any further in relation to STAU duration and TTAU duration, and hypothesis H5b is accepted as confirmed. Interestingly, the PAU means indicate that PAU duration remained fairly static under all conditions. For instance, in the comparison between AttentionType and Group, mean PAU duration for professional translators was 435 ms and for student translators 419 ms, and in the comparison between AttentionType and TimeConstraint, mean PAU duration was 423 ms under no time constraint, 435 ms under moderate time constraint and 428 ms under heavy time constraint. The apparently near-similar durations of the PAUs will be investigated inferentially in section 6.2.7.

In addition to the overall differences between STAU duration and TTAU duration, different patterns were observed for different combinations with the study's other three factors (Group, TextComplexity and TimeConstraint). More specifically, the LMER model showed that AttentionType entered into several significant interactions. Below, these interactions are examined in relation to hypothesis **H5a**, as relevant post-hoc comparisons were carried out to explain the significant interaction effects.

Interaction between AttentionType and Group

The very highly significant interaction effect of AttentionType and Group ($F = 201.2248$, $p < 0.0001$) suggested that differences between STAU duration and TTAU duration were affected by Group as they were different for professional translators and for student translators. The means illustrated in Figure 6.2c indicate that for professional translators, TTAUs were considerably longer in duration than STAUs (657 ms difference). For student translators, this difference was negligible (19 ms difference).

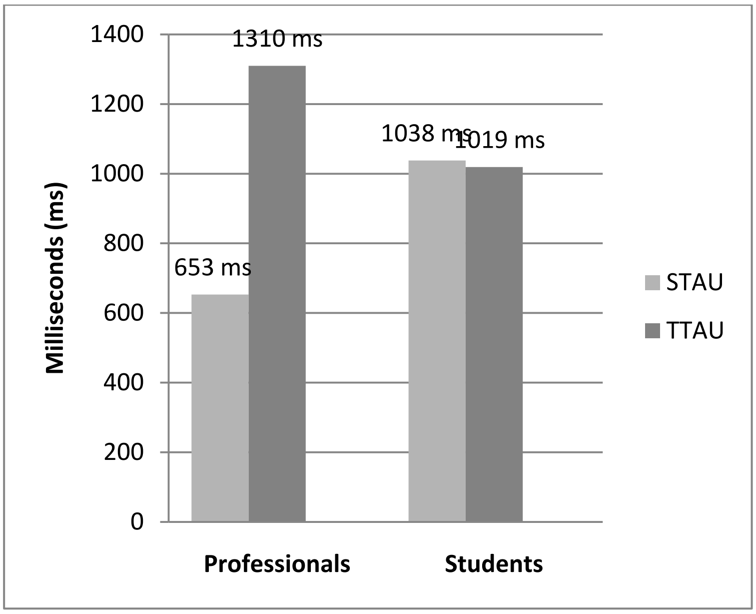

Figure 6.2c: AU duration: AttentionType and Group

Two post-hoc comparisons were performed between [Attention*ST*:Group*P*] and [Attention*TT*:Group*P*] and between [Attention*ST*:Group*S*] and [Attention*TT*:Group*S*] to investigate if the differences observed in the means were significant. The post-hoc comparisons showed that both differences were highly significant ($t = 34.57$, $p < 0.0001$, and $t = 7.36$, $p < 0.0001$, respectively). For both professional translators and student translators, the duration of TTAUs was significantly longer than that of STAUs (although the means in Figure 6.2c suggest that the student translators' STAUs were longer in duration than their TTAUs).[30]

It is interesting that the difference between the duration of the professional translators' STAUs and their TTAUs, as illustrated by the t-values, was much greater than the difference between the student translators' STAUs and their TTAUs. An explanation for the large difference between STAUs and TTAUs for professional translators could be that this group applies efficient comprehension strategies that enable them to efficiently extract and process relevant ST information while ignoring less relevant ST information. In other words, professional translators are able to very quickly establish a meaning hypothesis (Gile 1995: 102-105) which is reflected in the STAUs of relatively short duration. Considering Kintsch's (1988) construction-integration model, professional translators retain only some relevant propositions while irrelevant propositions are

[30] The surprising results of the second post-hoc comparison, which showed a positive effect, as illustrated in the t-value estimate in contrast to the negative difference in the descriptive means, is a good example of how interaction between several factors can affect the interpretation of a significant main effect; in this case, when considering AttentionType in relation to Group, it turns out that the difference in duration between STAUs and TTAUs is in fact opposite for student translators than the one indicated descriptively (see also section 5.3.3).

discarded without being stored in LTM (see section 3.2.1). With respect to TT processing, professional translators maintain attention focussed on TT processing for much longer than for ST processing. This could indicate that professional translators give high priority to TT reformulation, in response to the need for allocating sufficient cognitive resources to TT reformulation, in order to produce a good translation.

With respect to the smaller difference between STAUs and TTAUs for student translators, one explanation is that student translators *need* to focus attention on ST processing for longer periods of time in order to construct a meaning hypothesis; considering Kintsch's model, it could be that this group is slower at constructing propositions or that they store more propositions in LTM, which leads to STAUs of relatively longer durations. In turn, student translators' TTAUs were of relatively short durations which could indicate that they are not aware of the need to allocate sufficient cognitive resources to TT reformulation; as a consequence, this could have a negative impact on translation quality. Under the assumption that STAU and TTAU durations of *professional* translators reflect *good* management of cognitive resources, the suggestion could be hazarded that student translators do not *manage* the limited pool of cognitive resources as efficiently as professional translators since they give too low priority to TT processing.

After inclusion of Group in the analysis AttentionType, the hypothesis is still confirmed. The LMER model also showed that AttentionType and Group entered into a three-way interaction with TimeConstraint. Hypothesis **H5a** may only be partially confirmed if TimeConstraint is considered.

Interaction between AttentionType, Group and TimeConstraint

The interaction between AttentionType, Group and TimeConstraint just reached significance ($F = 2.3785$, $p = 0.0495$). The means that were relevant in the present analysis are presented in Figure 6.2d below. They indicate the same pattern that was illustrated by the means in Figure 6.2c, which showed that the difference between professional translators' STAUs and TTAUs was much greater than the difference between student translators' STAUs and TTAUs. The means presented in Figure 6.2d below indicate that the difference between STAU duration and TTAU duration became greater for professional translators when working under time pressure than when working under no time pressure. The difference for student translators working under both time conditions was less notable.

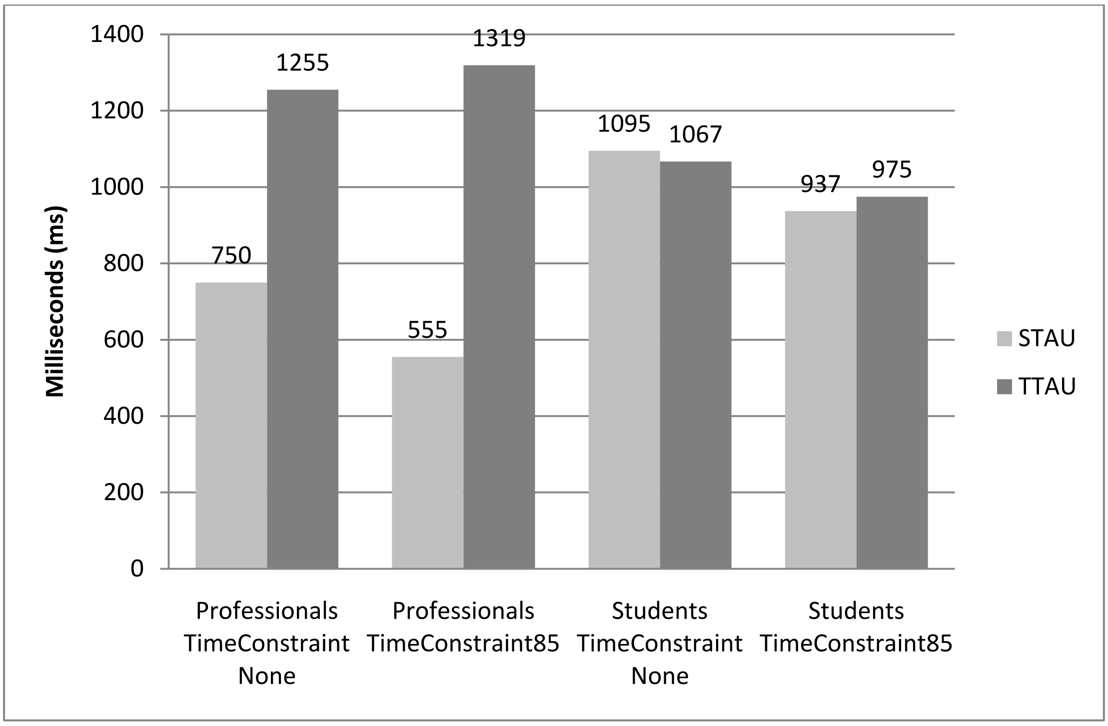

Figure 6.2d: AU duration: AttentionType, Group, and TimeConstraint

Four relevant post-hoc comparisons were carried out to examine if TTAUs were of longer duration than STAUs when both Group and TimeConstraint were considered. As explained in section 6.2.2 above, no post-hoc comparisons of factor-level TimeConstraint100 were carried out due to the Bonferroni problem; the post-hoc comparisons only consider the two extremities TimeConstraintNone and TimeConstraint85. The comparisons were: [Attention*ST*:Group*P*:Time*None*] and [Attention*TT*:Group*P*:Time*None*] ($t = 16.86$, $p < 0.0001$); [Attention*ST*:Group*P*:Time*85*] and [Attention*TT*:Group*P*:Time*85*] ($t = 22.69$, $p < 0.0001$); [Attention*ST*:Group*S*:Time*None*] and [Attention*TT*:Group*S*:Time*None*] ($t = 3.15$, $p = 0.0017$); and [Attention*ST*:Group*S*:Time*85*] and [Attention*TT*:Group*S*:Time*85*] ($t = 5.30$, $p < 0.0001$). Three of the comparisons (the first, second and fourth) confirmed that TTAUs were significantly longer than STAUs. The third comparison did not reach significance at the Bonferroni corrected p-level.

Bringing time pressure for professional translators into the picture, this analysis confirms that this group gives far higher priority to TT reformulation than to ST comprehension under both time conditions. In addition, the difference between STAU duration and TTAU duration was much larger under time pressure than under no time pressure. An explanation could be that professional translators, in response to the time pressure, adjust their allocation of cognitive resources so that TT reformulation is given slightly higher priority while ST comprehension is given considerably lower priority. For student translators, the difference is minimal, and it would seem that this group does not adjust the allocation of cognitive resources considerably under the two time conditions. So far, hypothesis **H5a** is still considered confirmed for professional translators and for student translators, although one post-hoc comparison for the latter group showed no significant effect.

Interaction between AttentionType and TimeConstraint

AttentionType also entered into a highly significant interaction with TimeConstraint (F = 8.9834, p = 0.0001). Mean STAU duration under TimeConstraintNone was 920 ms while mean TTAU duration was 1149 ms. Under TimeConstraint85, mean STAU duration was 746 ms and mean TTAU duration was 1118 ms, cf. Figure 6.2e below.

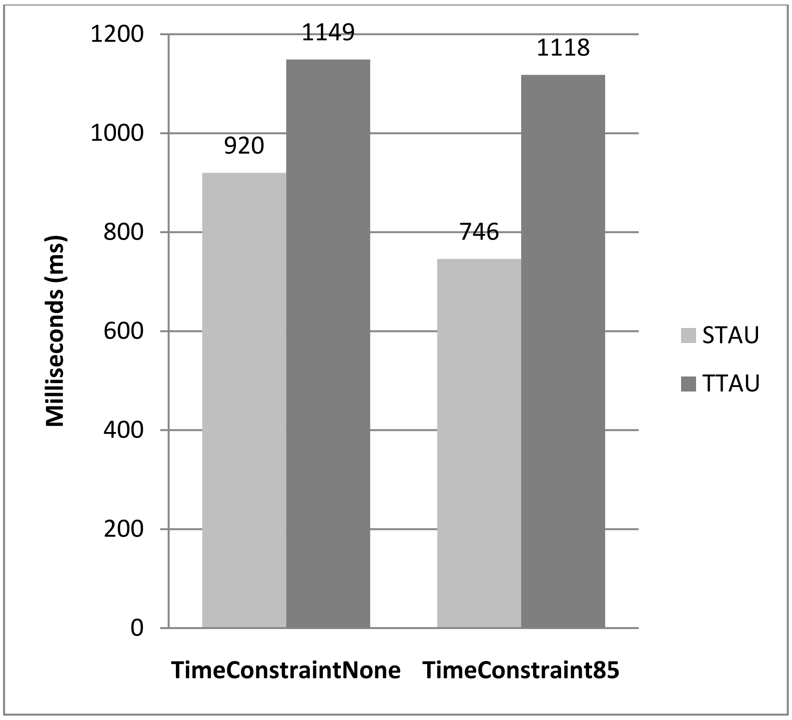

Figure 6.2e: AU duration: AttentionType and TimeConstraint

Two relevant post-hoc comparisons were carried out between [Attention*ST*:Time*None*] and [Attention*TT*:Time*None*] and [Attention*ST*:Time*85*] and [Attention*TT*:Time*85*]. Both comparisons revealed that TTAUs were significantly longer than STAUs under both time conditions (t = 14.04, p < 0.0001 and t = 19.27, p < 0.0001, respectively). The t-values indicate that the difference between TTAU and STAU means was largest under time constraint.

The previous analysis confirmed that professional translators and student translators responded differently to time pressure. When considering professional translators and student translators as *one* group in relation to AttentionType and

TimeConstraint, the difference in AU duration between STAUs and TTAUs was larger under time pressure than under no time pressure. Again, a likely explanation is that time pressure generally prompts the translator to allocate fewer cognitive resources to ST comprehension while the amount of cognitive resources allocated to TT reformulation is unchanged. This explanation, however, has to be regarded in relation to the analysis above which takes group differences into account.

The present analysis of the interaction effect between AttentionType and TimeConstraint is in full support of hypothesis **H5a**. AttentionType and TimeConstraint also entered into a very highly significant three-way interaction with TextComplexity, which could suggest that the hypothesis does not hold under some circumstances. This interaction is examined below.

Interaction between AttentionType, TimeConstraint and TextComplexity

The three-way interaction between AttentionType, TimeConstraint and TextComplexity was very highly significant ($F = 4.7451$, $p < 0.0001$). The relevant means, cf. Figure 6.2f below, show that mean STAU duration was systematically shorter than TTAU duration also when TimeConstraint and TextComplexity were considered together.

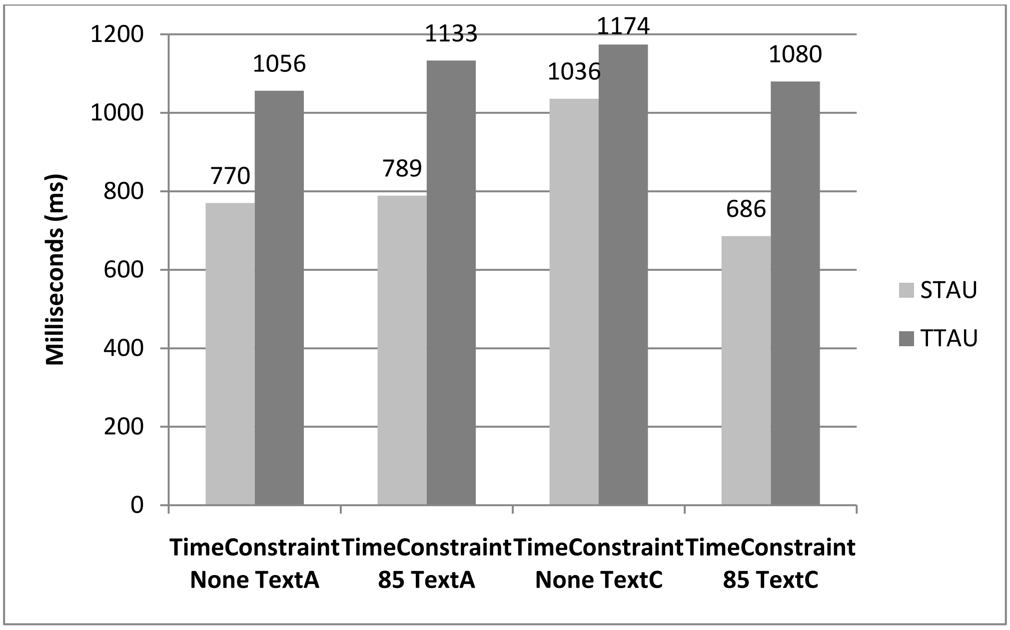

Figure 6.2f: AU duration: AttentionType, TimeConstraint and TextComplexity

Post-hoc comparisons were conducted to test if the differences between the pairs of means illustrated in the figure above were significant. As explained in section 6.2.2, no post-hoc comparisons of factor-level TextB were carried out due to the Bonferroni problem; the post-hoc comparisons only consider the two extremities TextA and TextC.: [Attention*ST*:Time*None*:Text*A*] and [Attention*TT*:Time*None*:Text*A*] (t = 9.14, p < 0.0001); [Attention*ST*:Time*85*:Text*A*] and [Attention*TT*:Time*85*:Text*A*] (t = 10.59, p < 0.0001); [Attention*ST*:Time*None*:Text*C*] and [Attention*TT*:Time*None*:Text*C*] (t = 8.01, p < 0.0001); and [Attention*ST*:Time*85*:Text*C*] and [Attention*TT*:Time*85*:Text*C*] (t = 12.38, p < 0.0001).

The comparisons showed that all differences were significant as TTAUs were consistently of significantly longer duration than STAUs when TextComplexity was taken into account in relation to AttentionType and TimeConstraint. In line with the previous post-hoc comparisons carried out above, the four conducted here show that the difference between STAU and TTAU duration was substantial. It seems that the inclusion of TextComplexity into the analyses did not affect the overall picture that TT reformulation is performed more slowly than ST comprehension. Interestingly, and perhaps not surprisingly, the final comparison indicates that translators' allocation of cognitive resources to ST comprehension and TT reformulation is affected most when translating difficult text under time pressure. In other words, when translating difficult text under time pressure, the translator gives higher priority to TT reformulating and lower priority to comprehending the ST. One consequence of such prioritisation could be that TT quality is affected negatively due to inadequate ST comprehension.

Summary and discussion (hypothesis H5a)

This section aimed at testing hypothesis **H5a**. The hypothesis stated that "TTAUs are of longer duration than STAUs." Table 6.2c below summarises the findings from this section:

Table 6.2c: Status of hypothesis H5a

Factor(s) / Status	Attention	Attention:Group	Attention:Group:Time
Confirmation	✓ TTAUs were longer than STAUs.	✓ For both groups, TTAUs were longer than STAUs.	✓ For professionals, TTAUs were longer than STAUs under no time constraint. ✓ For professionals, TTAUs were longer than STAUs under time constraint. ✓ For students, TTAUs were longer than STAUs under time constraint.
Modifier	*(none)*	*(none)*	- (*For students, TTAUs were not significantly longer than STAUs under no time constraint.*)
Factor(s) / Status		**Attention:Time**	**Attention:Time:Text**
Confirmation		✓ TTAUs were longer than STAUs under both time conditions.	✓ TTAUs were longer than STAUs for both texts under both time conditions.
Modifier		*(none)*	*(none)*

TTAUs were longer than STAUs under nearly all conditions, as indicated by 12 of the 13 post-hoc comparisons that were carried out to test hypothesis H5a, and the hypothesis is considered confirmed. There is only one exception, namely that TTAUs were not significantly longer than STAUs for student translators when translation is carried out under no time pressure. This comparison, however, did not show that the TTAUs were significantly shorter than the STAUs.

It was considered a likely explanation for the shorter STAUs that ST comprehension is less cognitively demanding as it is performed more quickly than TT reformulation. With respect to translational expertise, this explanation still holds when comparing AU duration for professional translators and student translators. More precisely, the analyses showed that both professional translators and student translators performed ST processing more quickly than they performed TT processing. However, there was a much larger difference between professional translators' STAU duration and TTAU duration than there was between the duration of student translators' STAUs and TTAUs. The large difference might be interpreted as evidence that professional translators are better at flexible adjusting their allocating of cognitive resources, whereas student translators do not exhibit flexibility to the same extent, and it is suggested that student translators are less capable of managing cognitive resources optimally. More specifically, student translators need to allocate a large amount of cognitive resources to ST comprehension while TT reformulation receives the same amount of resources. Bringing time pressure into the picture, the same general pattern emerges: professional translators respond flexibly to time pressure by giving lower priority to ST processing while higher priority is given to TT processing. Under both time conditions, the difference between the duration of student translators' STAUs and TTAUs remains largely the same, which indicate an inability to adjust under time pressure. Finally, the analysis which took into account source text complexity supported the general pattern that TT processing is somewhat slower and cognitively more demanding than ST processing. This issue of poor management of cognitive resources on the part of the student translators will be given some more consideration in relation to hypothesis H6 below.

6.2.4 AU duration and Group

This section will examine hypothesis **H6** which predicted that student translators' AUs are of longer duration than professional translators' AU. As illustrated in Table 6.2b above, there was no significant main effect of Group ($F = 1.1748$, $p = 0.3$). The professional translators' mean AU duration during translation was 909 ms while the student translators' mean AU duration was slightly longer at 928 ms. Although the descriptive means suggest some difference between professional translators' and student translators' AU durations in support of the hypothesis, no significant main effect was found by the LMER model. One tentative explanation for the apparently similar overall AU durations is that professional translators and student translators generally manage cognitive resources in much the same way. In other words, professional translators and student translators are not different when it comes to shifting the focus of attention. However, Group entered into several significant interactions, which indicates that differences in AU duration may be different for professional translators and student translators under certain conditions. Below, the significant interactions into which Group entered are examined more closely.

Interaction between Group and AttentionType

The very highly significant interaction between Group and AttentionType ($F = 201.2248$, $p < 0.0001$) suggests that professional translators and student translators differ with respect to the duration of their STAU and TTAUs. This interaction was also discussed in section 6.2.3 above, but its main focus there was on within-group differences, whereas the main focus here is on between-group differences.

In Figure 6.2g below, mean duration values for each type of AU are presented across Group. The STAU means show that professional translators' STAUs (653 ms) were shorter in duration than student translators' (1038 ms). The TTAU means were interestingly substantially longer in duration for professional translators (1310 ms) than for student translators (1019 ms). The differences in the means indicate that the hypothesis can only be partially confirmed, as student translators' TTAUs are shorter than those of the professional translators.

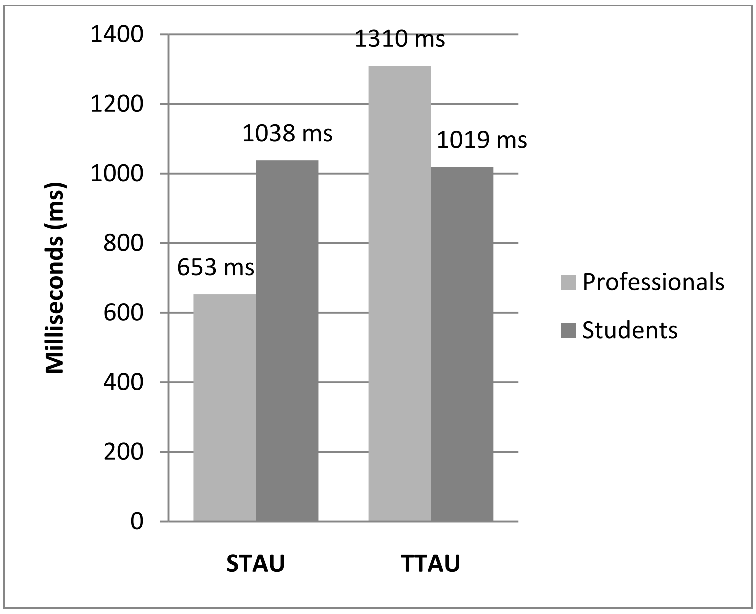

Figure 6.2g: AU duration: Group and AttentionType

To investigate this further, two post-hoc comparisons were conducted between [Group*P*:Attention*ST*] and [Group*S*:Attention*ST*] and between [Group*P*:Attention*TT*] and [Group*S*:Attention*TT*]. Both comparisons were significant ($t = 6.01$, $p < 0.0001$, and $t = -3.33$, $p < 0.0001$, respectively), and they confirmed the indication by the means. At this point, the hypothesis is partially confirmed as only STAUs were of longer duration and not TTAUs, which were in fact of significantly shorter duration.

With respect to ST processing, student translators allocate considerably more cognitive resources to ST comprehension than professional translators. This is perhaps not surprising since student translators *need* to spend more time extracting ST meaning. Professional translators are capable of arriving at a meaning hypothesis much more quickly than student translators since they, by virtue of more familiarity in reading with the specific purpose of translating, have developed efficient comprehension strategies. This was already suggested in section 6.2.3 above; it is emphasised here, however, by the considerable difference between professional translators and student translators. With respect to the professional translators' somewhat longer TTAUs, in comparison with those of the student translators, one explanation is that professional translators give higher priority to TT reformulation. Student translators in turn give too low priority to TT reformulation. This was also suggested in section 6.2.3 above.

The LMER model showed that Group and AttentionType entered into a significant interaction with TimeConstraint. The comparisons below examine if and to what extent the introduction of TimeConstraint had an effect on the validity of the hypothesis.

Interaction between Group, AttentionType and TimeConstraint

The interaction between Group, AttentionType and TimeConstraint just reached significance ($F = 2.3785$, $p = 0.0495$). The means in Figure 6.2h show that professional translators' STAUs were shorter than those of the student translators under both time conditions. With respect to TTAUs, the difference was in the opposite direction as the professional translators' TTAUs were longer in duration than those of student translators. Interestingly, the difference between the means seems to be larger when translating under a time constraint than when translating under no time constraint.

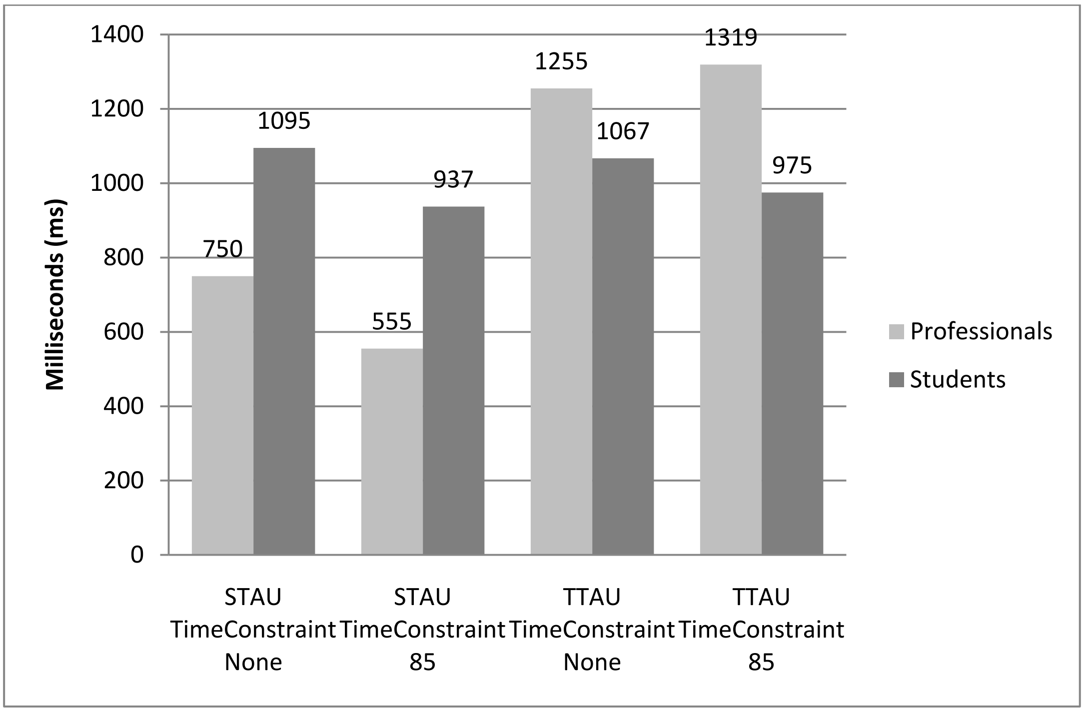

Figure 6.2h: AU duration: Group, AttentionType and TimeConstraint

Four relevant post-hoc comparisons were conducted to examine if the differences indicated by the means were significant. The comparisons and the results were [Group*P*:Attention*ST*:Time*None*] and [Group*S*:Attention*ST*:Time*None*] (t = 4.92, p < 0.0001); [Group*P*:Attention*ST*:Time*85*] and [Group*S*:Attention*ST*:Time*85*] (t = 5.57, p < 0.0001); [Group*P*:Attention*TT*:Time*None*] and [Group*S*:Attention*TT*:Time*None*] (t = -1.92, p = 0.05); and [Group*P*:Attention*TT*:Time*85*] and [Group*S*:Attention*TT*:Time*85*] (t = -4.11, p < 0.0001).

The two post-hoc comparisons to do with STAUs partially confirm hypothesis **H6** as student translators' STAUs were longer than those of professional translators under both time conditions. With respect to TTAUs, neither of the two comparisons to do with TTAU confirms the hypothesis. Under no time constraint, there is no significant difference between professional translators' and student translators' TTAUs, and under time constraint, professional translators' TTAUs were in fact significantly longer than student translators' TTAUs.

The explanation proposed above and in section 6.2.3 that professional translators, compared to student translators, far more quickly arrive at meaning hypotheses is also expressed in the present analysis which considers time pressure. Taking time pressure into account, the difference, as indicated by the t-values, seems to be larger under time pressure than under no time pressure. This suggests that professional translators allocate fewer cognitive resources to ST processing under time pressure than do student translators. With respect to TT processing, it is not possible to say much about the difference under no time pressure since it was not significant; however, it is clear that student translators give somewhat lower priority to TT reformulation under time pressure than do the professional translators.

Interaction between Group and TimeConstraint

The LMER model showed a significant interaction between Group and TimeConstraint (F = 3.1865, p = 0.0413). The relevant means (see Figure 6.2i) show that mean AU duration under no time constraint for professional translators (925 ms) was shorter than for student translators (980 ms). With respect to the means under time constraint, the difference was in the opposite direction as the mean AU duration for professional translators (872 ms) was slightly longer than for student translators (868 ms).

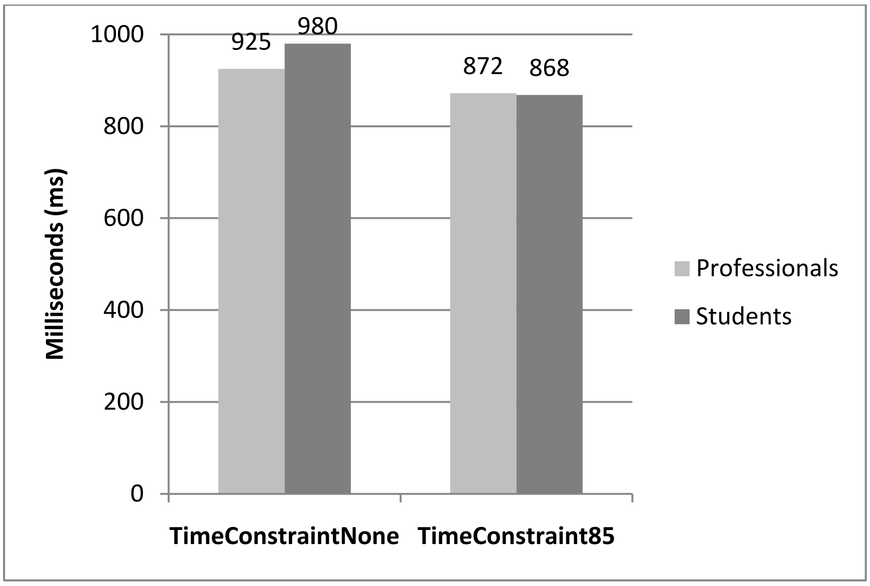

Figure 6.2i: AU duration: Group and TimeConstraint

Two post-hoc comparisons were carried out to examine if the differences between the groups under different time conditions were significant: [Group*P*:Time*None*] and [Group*S*:Time*None*] and [Group*P*:Time*85*] and [Group*S*:Time*85*]. The first comparison did not reach significance (t = 1.64, p = 0.1). Although the means indicated that the duration of professional translators' AUs was 55 ms shorter than the student translators', the post-hoc comparison showed no significant effect. The second post-hoc comparison between the two groups' AU duration when translating under time constraint also did not reach significance (t = 0.69, p = 0.5).

The non-significant results indicate that professional translators and student translators do *not* allocate cognitive resources to translation differently under no time pressure and under time pressure. This explanation makes little sense, however, considering that the comparisons of Group and AttentionType and Group, AttentionType and TimeConstraint, above, in fact showed that there *are* significant differences between professional translators and student translators when STAUs and TTAUs are considered. The results of the non-significant comparisons here should therefore be considered provisional, as they do not take into account differences between AttentionType.

Interaction between Group, TimeConstraint and TextComplexity

One factor, which has not been discussed in relation to the two groups' management of cognitive resources, is source text complexity. The overall LMER analysis only showed one interaction with Group and TextComplexity, namely a three-way interaction which included TimeConstraint. It may be that overall AU durations differed between professional translators and student translators under the time conditions when taking into account also TextComplexity. The LMER analysis showed a highly significant three-way interaction between Group, TextComplexity and TimeConstraint (F = 4.6814, p = 0.0009). Considering first the means, cf. Figure 6.2j, there was no clearly identifiable pattern in the differences in AU duration between professional translators and student translators; there were, however, some large differences between the means of some of the comparisons.

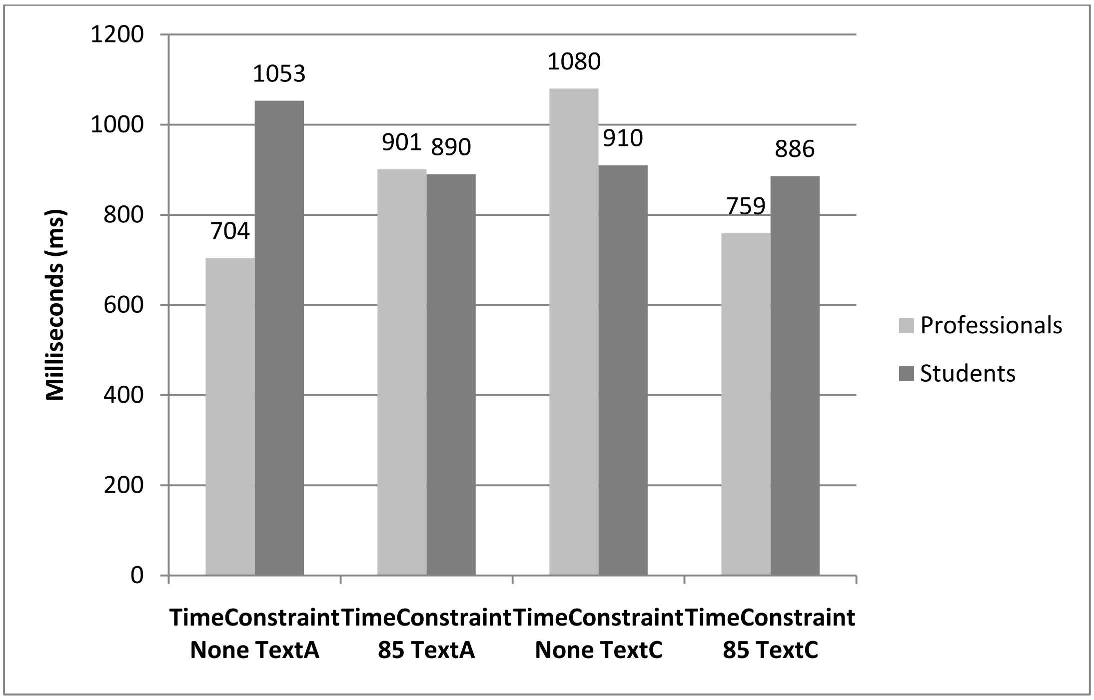

Figure 6.2j: AU duration: Group, TimeConstraint and TextComplexity

Four relevant post-hoc comparisons were conducted to investigate if the differences reached significance. The comparisons were: [Group*P*:Time*None*:Text*A*] and [Group*S*:Time*None*:Text*A*] (t = 3.80, p = 0.0001); [Group*P*:Time*85*:Text*A*] and [Group*S*:Time*85*:Text*A*] (t = 1.76, p = 0.08); [Group*P*:Time*None*:Text*C*] and [Group*S*:Time*None*:Text*C*] (t = -1.43, p = 0.2); and [Group*P*:Time*85*:Text*C*] and [Group*S*:Time*85*:Text*C*] (t = 1.28, p = 0.2).

Three of the four post-hoc comparisons did not reach significance. There was one comparison which reached significance: professional translators' AUs were significantly shorter than those of student translators when they translated TextA under no time pressure. The analysis of the present three-way interaction does not take into account differences between STAU duration and TTAU duration, and one explanation for the non-significant comparisons is likely to be that differences between ST comprehension and TT reformulation are not investigated. Had STAU duration and TTAU duration also been investigated in a four-way interaction,[31] then it is probable that significant differences would have been observed. Hypothesis **H6** is therefore still considered partially confirmed, as it was established earlier that it is differences between the two groups' STAUs and TTAUs that separate professional translators and student translators from each other.

Summary and discussion (hypothesis H6)

12 relevant post-hoc comparisons were carried out to test hypothesis **H6**. The hypothesis stated that "AUs are of longer duration for student translators than for professional translators". A summary of the findings from the post-hoc comparisons is presented in Table 6.2d below:

[31] Post-hoc comparisons between four-factor cells are not carried out due to the problem of the risk of Type II statistical errors (see also sections 5.3.3 and 6.2.2).

Table 6.2d: Status of hypothesis H6

Factor(s) / Status	Group	Group:Attention	Group:Attention:Time
Confirmation	*(no significant main effect.)*	✓ Students' STAUs were longer than professionals' STAUs.	✓ Students' STAUs were longer than professionals' STAUs under both time conditions.
Modifier		÷ Students' TTAUs were shorter than professionals' TTAUs.	÷ Students' TTAUs were shorter than professionals' TTAUs under time constraint. - (*Students' TTAUs were not significantly longer than professionals' TTAUs under no time constraint.*)
Factor(s) / Status		**Group:Time**	**Group:Time:Text**
Confirmation		*(none)*	✓ Students' AUs were longer than professionals' AUs under no time constraint for less complex texts.
Modifier		- (*Students' AUs were not significantly longer than professionals' AUs under either time condition.*)	- (*Students' AUs were not significantly longer than professionals' AUs under time constraint for both texts.*) - (*Students' AUs were not significantly longer than professionals' AUs under no time constraint for complex texts.*)

The main effect of Group turned out to be non-significant, which could indicate that there is no support for hypothesis H6. The lack of significance does not come as a surprise however, since the post-hoc comparisons carried out in relation to the interactions between Group and AttentionType and between Group, AttentionType and TimeConstraint found that only student translators' *STAUs* were longer than professional translators', and not their *TTAUs*, which were generally shorter for student translators. All but one of the comparisons that did not consider AttentionType turned out to be non-significant, which indicates that the differences between the two groups were driven by differences between STAU duration and TTAU duration. Based on the review of the post-hoc comparisons, hypothesis H6 is partially confirmed as STAUs were longer for student translators than for professional translators under various conditions while TTAUs were shorter. Based on the post-hoc comparisons, professional translators allocate cognitive resources to ST comprehension for *shorter* periods of time than do student translators;

with respect to TT reformulation it is the opposite, as professional translators allocate cognitive resources to TT reformulation for *longer* periods of time than student translators.

In this section, the large difference between the two groups' STAUs was speculated to relate to the fact that student translators do not apply the same comprehension strategies as professional translators. Professional translators are much better at quickly arriving at a plausible meaning of the ST, whereas student translators need more time to do so. It may be that this latter group is slower at performing lexical and propositional analyses than the former group, simply because they have developed the same efficient comprehension strategies.

The large difference between TTAUs was proposed to relate to professional translators' awareness of the need to allocate sufficient cognitive resources to reformulating the ST message in the TL. Student translators give comparatively lower priority to TT reformulation, possibly because they are not as aware as are the professional translators of the need to allocate cognitive resources for long enough in order to arrive at a good rendition of the ST message in the TL. In other words, student translators become satisfied with a translation of the ST more quickly than professional translators, although the translation might not be qualitatively acceptable. This proposal could to be examined closer by assessing TT quality.

Another issue, which might also explain why professional translators' TTAUs are of longer duration than those of the student translators, has to do with typing skills. It might be that professional translators type more words before pausing than student translators, which could be expressed in longer TTAUs. This is not an unreasonable proposal; Dragsted (2004: 164 and 234) found that the size of professional translators' translation segments, as indicated by pauses in writing, were longer (around 20 percent) than those of the student translators. Based on this observation, it could be that the shorter TTAUs are not a result of poor management of cognitive resources but rather a result of different typing skills. The present study does not estimate to what extent it is typing skills and to what extent it is the less than optimal management of cognitive resources which are responsible for the relatively short TTAUs on the part of the student translators. It is nonetheless considered likely that *both* of these circumstances have an effect on TTAU duration. The shorter TTAUs on the part of the student translators are therefore assumed to relate to a combination of typing skills and cognitive management skills. This proposal would have to be tested further in future studies.

6.2.5 AU duration and TextComplexity

This section will discuss hypothesis **H7**, which stated that AUs are of longer duration for difficult source texts than for easy source texts. Mean AU duration for TextA was 897 ms, somewhat longer for TextB at 927 ms and 931 ms for TextC. Although the means illustrate a 34 ms increase in mean AU duration from the least complex TextA to the most complex TextC, the results of the LMER model presented in Table 6.2b showed that the overall effect was non-significant ($F = 2.1716$, $p = 0.1$). There is so far no statistical support for this hypothesis. Two-way interactions were also not able to support the hypothesis since TextComplexity did not enter into any significant two-way interactions. TextComplexity did enter into two significant three-way interactions, but since there were no significant two-way interactions to motivate examination of post-hoc comparisons, none were carried out.

An explanation for the lack of significant main effects and two-way interaction effects, which was proposed in relation to hypothesis H3, was that there were too few data points on which to base statistical analysis. This proposition seemed relevant in that discussion since there were only 216 data points; however, the present analysis was based on nearly 23,000 data points, which is considered a sufficient amount of data, and this explanation is therefore rejected.

Another explanation is that source text difficulty generally does not affect AU duration. Although a complex source text is experienced as being more difficult than a less complex source text, translators manage cognitive resources in a similar manner. This means that translators' shifting of attention between the ST and the TT is not affected by source text difficulty as it will occur with similar intervals. It might still be that the text is perceived as more difficult, although this does not affect AU duration. This explanation relies on confirmation of hypothesis H11 in section 6.3.4, which used pupil size as an indicator of cognitive load. This hypothesis also was not confirmed, and this proposed explanation is therefore rejected.

A third explanation, which was also suggested in section 6.1.4, is that the translators did not experience any difference between the texts with respect to source text difficulty. The three source texts that were used in this study were designed to be different from each other through the employment of a number of complexity indicators: readability, word frequency and non-literal expressions. It is possible that the texts were in fact not perceived as being different with respect to comprehension difficulty by the translators, in spite of the complexity indicators demonstrating considerable differences with respect to complexity. The present study would most likely have benefited from qualitative interview data of the translators' experience of the experimental texts. These data could have given some indication of the translators' experience of the texts with respect to differences in their levels of difficulty. This explanation seems to be the most plausible one, considering the other explanations, but it would have to be explored in some more detail in future studies using different pairs of texts.

6.2.6 AU duration and TimeConstraint

In the following, hypothesis **H8** will be investigated. The hypothesis stated that AUs are of shorter duration when translating a text under time pressure than when translating a text under no time pressure. The LMER model indicated very highly significant differences in AU duration between the three levels of time constraint (F = 13.9757, p < 0.0001). Mean AU duration when translating under no time constraint (TimeConstraintNone) was highest at 953 ms. Mean AU duration under the moderate time constraint (TimeConstraint100) was 927 ms, and mean AU duration under the heavy time constraint (TimeConstraint85) was lowest at 870 ms.

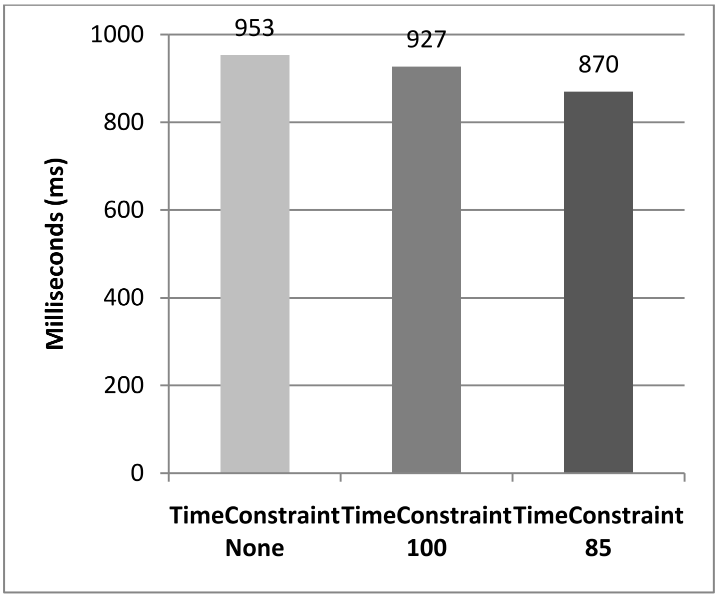

Figure 6.2k: AU duration: TimeConstraint

The descriptive figures provide some support for the hypothesis, but in order to test this inferentially, three post-hoc comparisons were carried out between [Time*None*] and [Time*85*]; [Time*None*] and [Time*100*]; and [Time*100*] and [Time*85*]. The first comparison showed a significant difference (t = -4.99, p < 0.0001) in AU duration between texts translated under no time constraint and texts translated under the heaviest time constraint. This means that heavy time pressure affected AU duration. The second comparison did not reach significance (t = -2.02, p = 0.0432). AU duration was not significantly shorter under moderate time pressure than under no time pressure. The third comparison which compared moderate time pressure and heavy time pressure also did not reach significance (t = -2.94, p = 0.0033) at the Bonferroni corrected p-level.

Based on the post-hoc comparisons above, it may provisionally be concluded that the hypothesis is partially confirmed, as AU duration was affected when comparing translations that had been translated under no time pressure and translations that had been translated under heavy time pressure. One explanation for the inconclusiveness of the comparisons concerning TimeConstraint100 could be that this level of time constraint was experienced very differently by the study's participants. More precisely, some participants might have experienced TimeConstraint100 as heavy time pressure while other participants might not at all have had an experience of time pressure. If this is the case, then the inclusion of this factor level could affect negatively the outcome of the present analysis to do with hypothesis H8. There is, nevertheless, still a very strong effect of the comparison between the two factor levels TimeConstraintNone and TimeConstraint85, and for this reason, and also due to the Bonferroni problem of multiple comparisons (see sections 5.3.3 and 6.2.2), the analysis of hypothesis H8 will concern only these two levels. In the light of this decision to leave out TimeConstraint100, the hypothesis is considered confirmed.

It is not all that surprising that AU duration is shorter under time pressure (TimeConstraint85) than under no time pressure (TimeConstraintNone) since less time is available to construct meaning hypotheses and to reformulate the ST message in the TL (see section 3.1.4.1). The translator will therefore shift her focus of attention between the ST and the TT more frequently. This observation will be given more consideration below as TimeConstraint entered into several significant interactions.

It should be noted that it might have been that time pressure would have forced the translator to work with larger attention units, covering more ST content and TT content, as a strategy intended to optimise her allocation of cognitive resources. This does not seem to be the case, and instead more or less the same amount of ST content and TT content is processed in less time.

Interaction between TimeConstraint and AttentionType

The LMER analysis showed that the interaction between TimeConstraint and AttentionType was highly significant (F = 8.9834, p = 0.0001). The relevant means (see also Figure 6.2l) show that mean duration for STAUs was 920 ms under no time constraint and 746 ms under time constraint. Mean TTAU duration was 1149 ms under no time constraint and 1118 ms under time constraint. The difference between the means was greatest for STAUs and considerably smaller for TTAUs.

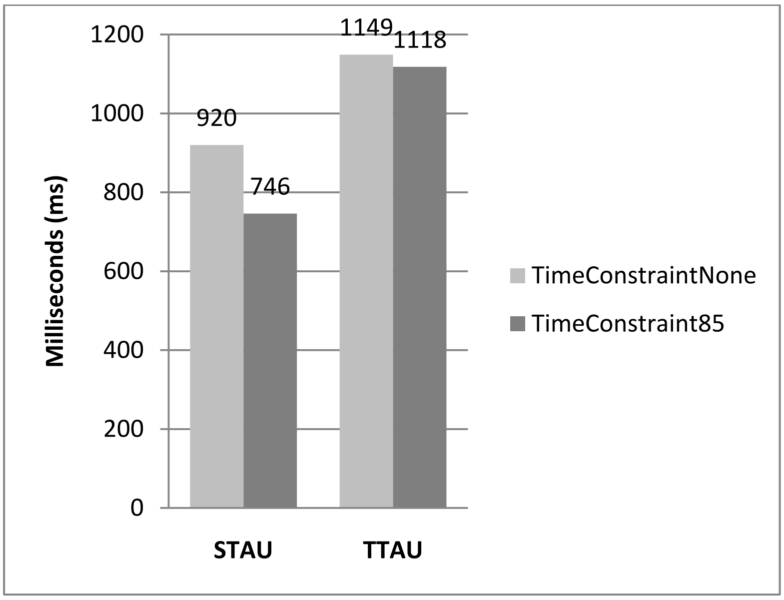

Figure 6.2I: AU duration: TimeConstraint and AttentionType

Two post-hoc comparisons were conducted to investigate if the differences were significant. The first comparison between [Time*None*:Attention*ST*] and [Time*85*:Attention*ST*] showed that this difference was significant ($t = -6.62$, $p < 0.0001$). The second comparison between [Time*None*:Attention*TT*] and [Time*85*:Attention*TT*] did not reach significance ($t = -0.70$, $p = 0.5$). Hypothesis **H8** is partially confirmed as STAU duration was shorter under time pressure than under no time pressure, whereas TTAU duration did not change significantly.

The first comparison shows that cognitive resources were allocated to ST meaning extraction for shorter periods of time as STAUs were of shorter durations under time pressure than under no time pressure. Interesting is it, however, that TTAU duration is not significantly different under the two time conditions. A probable explanation for this observation is that (1) ST comprehension involves flexible allocation of cognitive resources, which is adjusted according to time pressure, and (2) the allocation of cognitive resources to TT reformulation is more static, in the sense that the amount of resources allocated to its processing does not change under time pressure. So, when the translator is translating under time pressure it is comprehension rather than reformulation that is affected. One consequence of the shorter time spent on each STAU under time pressure could be that comprehension receives too few cognitive resources, which could affect translation quality negatively.

The interaction between TimeConstraint and AttentionType entered into a significant three-way interaction with Group. It may be that the explanation of flexible ST comprehension and static TT reformulation does not pertain to both professional translators and student translators. This interaction will be examined closer below.

Interaction between TimeConstraint, AttentionType and Group

The interaction between TimeConstraint, AttentionType and Group just reached significance ($F = 2.3785$, $p = 0.0495$). The means (see Figure 6.2m) show that both professional translators' and student translators' STAUs were considerably longer under no time constraint than under time constraint. With respect to TTAUs, professional translators' TTAUs were of shorter durations under no time constraint than under time constraint, while it was the opposite for student translators.

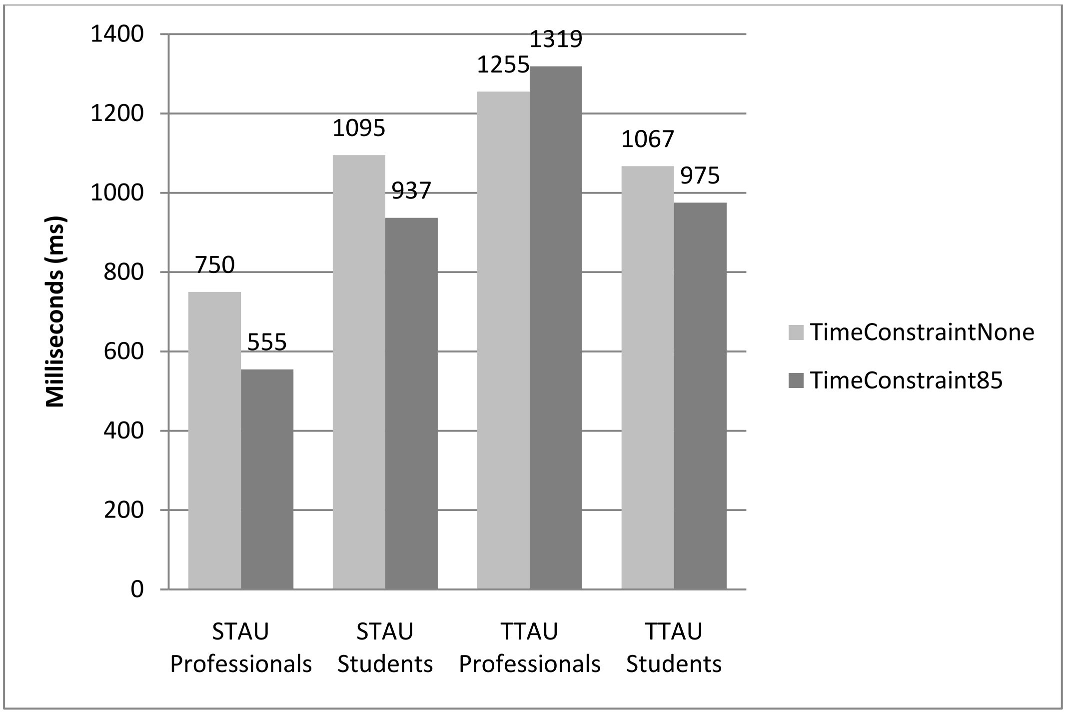

Figure 6.2m: AU duration: TimeConstraint, AttentionType and Group

Four relevant post-hoc comparisons were carried out to test if these differences were significant. The comparisons were [Time*None*:Attention*ST*:Group*P*] and [Time*85*:Attention*ST*:Group*P*] ($t = -5.51$, $p < 0.0001$); [Time*None*:Attention*ST*:Group*S*] and [Time*85*:Attention*ST*:Group*S*] ($t = -4.00$, $p = 0.0001$); [Time*None*:Attention*TT*:Group*P*] and [Time*85*:Attention*TT*:Group*P*] ($t = 2.39$, $p = 0.0171$); and [Time*None*:Attention*TT*:Group*S*] and [Time*85*:Attention*TT*:Group*S*] ($t = -2.78$, $p = 0.0054$).

The post-hoc comparisons confirm that STAU duration, for both professional translators and student translators, was shorter under time pressure, supporting hypothesis **H8**. The post-hoc comparisons did not reach statistical significance with respect to the duration of professional translators' and student translators' TTAUs. These findings are consistent with those of the interaction above, which considered TimeConstraint and AttentionType. The present analysis offers some modification of the overall picture as it appears that the difference for STAU duration for professional translators is greater than it is for student translators. This observation supports the findings from sections 6.2.3 and 6.2.4, which indicated that professional translators are better than student translators at adjusting the allocation of cognitive resources to meet the requirements of the translation task with respect to its comprehension. In other words, professional translators are better than student translators at economising the limited pool of cognitive resources. With respect to the static TTAUs, it seems that TT reformulation, for both professional translators and student translators is inflexible as the amount of time spent in each TTAU is more or less the same under both time conditions. This observation mirrors the one made above in relation to the interaction between TimeConstraint and AttentionType. Overall, hypothesis H8 is still partially confirmed.

In addition to the three-way interaction examined here, TimeConstraint and AttentionType also entered into a significant interaction with TextComplexity. This interaction will be examined below.

Interaction between TimeConstraint, AttentionType and TextComplexity

The three-way interaction between TimeConstraint, AttentionType and TextComplexity was very highly significant ($F = 4.7451$, $p < 0.0001$). The means (see Figure 6.2n) that were relevant showed no systematic pattern; there was however one large difference between STAU duration in the translation of TextC under time constraint (1036 ms) and under no time constraint (686 ms).

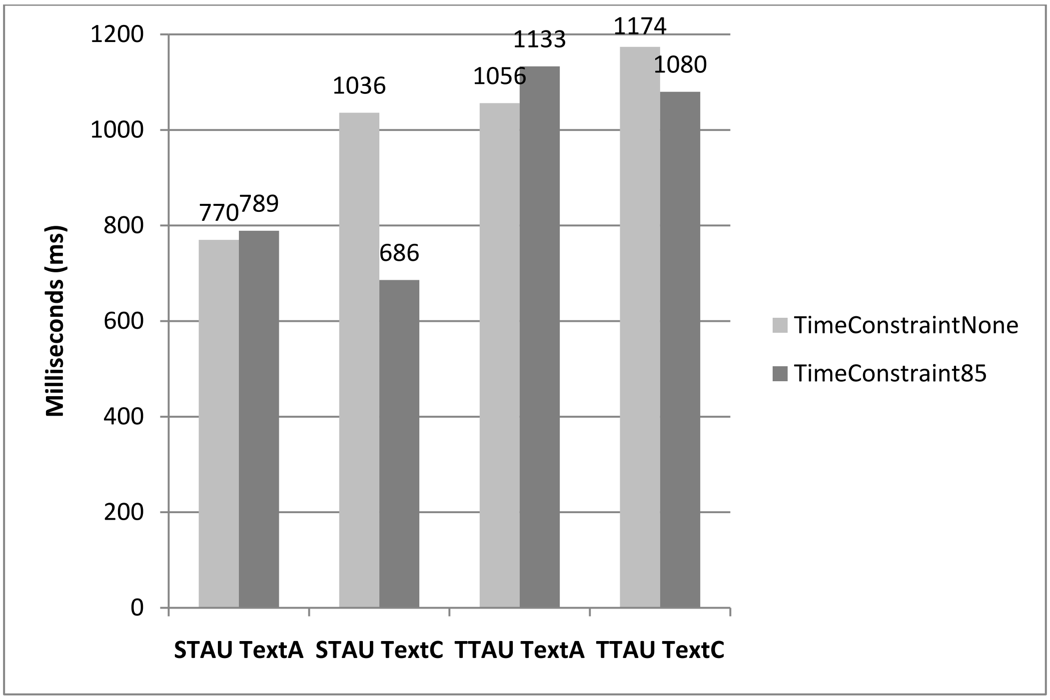

Figure 6.2n: AU duration: TimeConstraint, AttentionType and TextComplexity

To see if the differences were significant, four post-hoc comparisons were conducted: [Time*None*:Attention*ST*:Text*A*] and [Time*85*:Attention*ST*:Text*A*] (t = -0.62, p = 0.5); [Time*None*:Attention*ST*:Text*C*] and [Time*85*:Attention*ST*:Text*C*] (t = -2.92, p = 0.0035); [Time*None*:Attention*TT*:Text*A*] and [Time*85*:Attention*TT*:Text*A*] (t = 0.47 , p = 0.6); and [Time*None*:Attention*TT*:Text*C*] and [Time*85*:Attention*TT*:Text*C*] (t = -0.89, p = 0.4).

None of the comparisons reached significance at the Bonferroni corrected p-level. The inconclusiveness of the post-hoc comparisons conducted here suggests that source text complexity does not affect AU duration. More specifically, it could seem that translators manage their cognitive resources in more or less the same way when translating a difficult text and when translating an easy text. It is, however, also a likely explanation that the introduction of source text complexity into the analysis distorts the overall picture somehow and obscures the significant effects concerning time pressure. This explanation is supported by the findings from section 6.2.5, which strongly indicated that source text complexity, in the present study, does not affect the management of cognitive resources.

Interaction between TimeConstraint and Group

The LMER model showed a weak interaction between TimeConstraint and Group (F = 3.1865, p = 0.0413). In Figure 6.2o below, the means suggest that overall AU duration for both professional translators and student translators was shorter under time constraint than under no time constraint. For professional translators, mean AU duration under no time constraint (925 ms) was longer than mean AU duration under time constraint (872 ms), and with respect to student translators, mean AU duration under no time constraint (980 ms) was longer than mean AU duration under time constraint (868 ms).

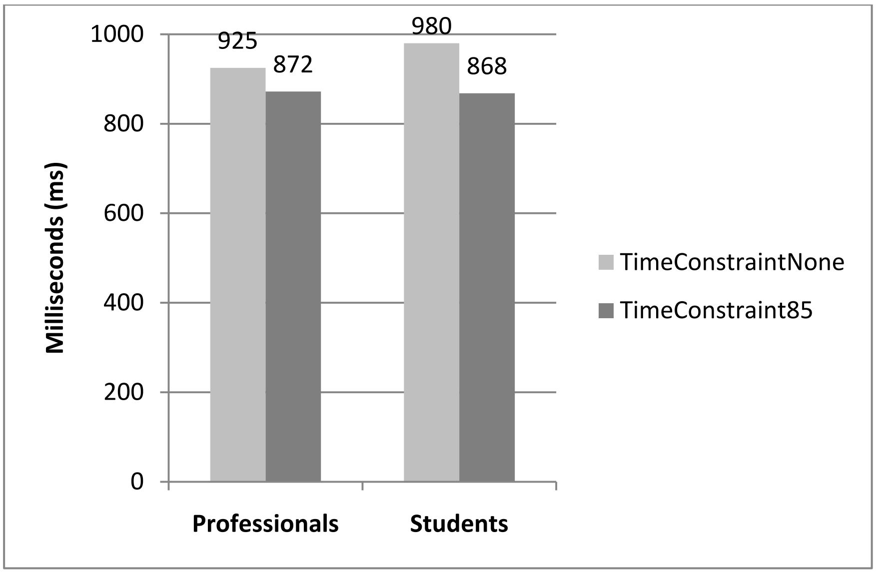

Figure 6.2o: AU duration: TimeConstraint and Group

Two post-hoc comparisons were conducted to examine if the differences were significant. The comparisons were: [Time*None*:Group*P*] and [Time*85*:Group*P*] (t = -2.12, p = 0.0338) and [Time*None*:Group*S*] and [Time*85*:Group*S*] (t = -4.88, p < 0.0001). The first comparison did not support the indication in the means since it did not reach significance. The second comparison showed that student translators' mean AU duration was indeed shorter under time pressure than under no time pressure. Interestingly, the comparisons indicate that it is the student translators who respond to time pressure as overall AU duration drops, while there is no significant difference for the professional translators. This comes as a surprise since there was indication earlier that student translators are less capable of adjusting the allocation of cognitive resources. This finding should, however, be considered provisional, as the discussion to do with TimeConstraint, Group and AttentionType above provided a more detailed account of professional translators' and student translators' reaction to time pressure.

Interaction between TimeConstraint, Group and TextComplexity

According to the LMER model, there was a highly significant effect of the three-way interaction between TimeConstraint, Group and TextComplexity (F = 4.6814, p = 0.0009). The means illustrated in Figure 6.2p below indicate that the duration of professional translators' AUs, for the less complex TextA, was actually longer under time constraint than under no time constraint. With respect to the more complex TextC, professional translators' mean AU duration was shorter under time constraint than no under time constraint. For student translators, mean AU duration, for both texts, was shorter under time constraint than under no time constraint.

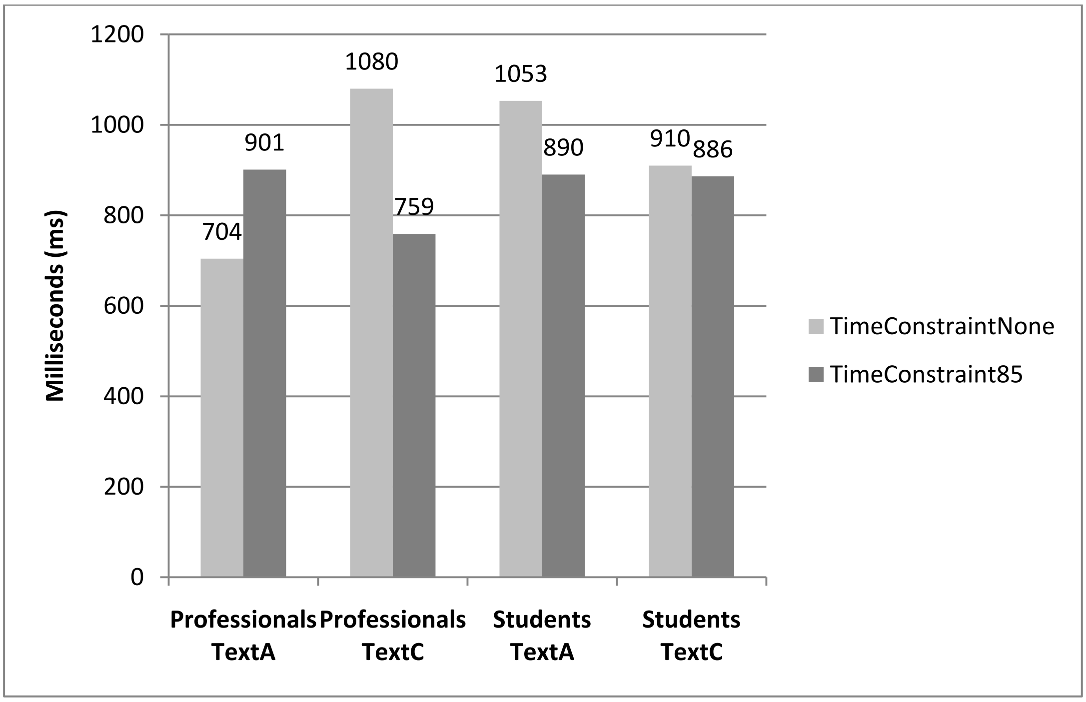

Figure 6.2p: AU duration: TimeConstraint, Group and TextComplexity

In order to test if the differences were significant, four post-hoc comparisons were carried out: [Time*None*:Group*P*:Text*A*] and [Time*85*:Group*P*:Text*A*] (t = 0.64, p = 0.5); [Time*None*:Group*P*:Text*C*] and [Time*85*:Group*P*:Text*C*] (t = -2.98, p = 0.0029); [Time*None*:Group*S*:Text*A*] and [Time*85*:Group*S*:Text*A*] (t = -1.39, p = 0.2); and [Time*None*:Group*S*:Text*C*] and [Time*85*:Group*S*:Text*C*] (t = 1.43, p = 0.2). None of the comparisons turned out to be significant. The significant effect of the interaction was therefore likely to have been driven by differences other than the ones investigated here (for the significant comparisons, see sections 6.5.3 and 6.5.4). This specific analysis takes TextComplexity into consideration, and it is likely here also that the presence of

TextComplexity obscured the effects of time pressure so that the findings turned out to be non-significant.

Summary and discussion (hypothesis H8)

19 relevant post-hoc comparisons were carried out to test hypothesis **H8** under various conditions. The hypothesis stated that “AUs are of shorter duration under time pressure than under no time pressure”. Table 6.2e below provides a summary of the findings of the post-hoc comparisons:

Table 6.2e: Status of hypothesis H8

Factor(s) / Status	Time	Time:Attention	Time:Attention:Group
Confirmation	✓ AUs were shorter under time constraint than under no time constraint.	✓ STAUs were shorter under time constraint than under no time constraint.	✓ For both groups, STAUs were shorter under time constraint than under no time constraint.
Modifier	*(none)*	- *(TTAUs were not significantly shorter under time constraint than under no time constraint.)*	- *(For both groups, TTAUs were not significantly shorter under time constraint than under no time constraint.)*
Factor(s) / Status			**Time:Attention:Text**
Confirmation			*(none)*
Modifier			- *(For both texts, STAUs and TTAUs were not significantly shorter under time constraint than under no time constraint.)*
Factor(s) / Status		**Time:Group**	**Time:Group:Text**
Confirmation		✓ Students' AUs were shorter under time constraint than under no time constraint.	*(none)*
Modifier		- *(Professionals' AUs were not significantly shorter under time constraint than under no time constraint.)*	- *(For both groups and both texts, AUs were not significantly shorter under time constraint than under no time constraint.)*

The summary shows that hypothesis H8 is partially confirmed. Although *overall* AU duration was shorter under time constraint than under no time constraint, it was in fact only *STAU* duration which was shorter when considering the interactions to do with AttentionType; *TTAU* duration remained roughly the same under both time conditions. Considering professional translators and student translators separately, the same pattern emerged as STAU duration for both groups was shorter under time constraint and TTAU duration was unaffected. The comparisons that considered source text complexity did not turn out to be significant, and it was considered likely that source text complexity somehow obscured the effects to do with time constraint (see also section 6.2.5).

The present analysis of hypothesis H8 strongly suggests that time pressure only affected ST comprehension and not TT reformulation. For both groups, TT reformulation is fairly static as illustrated by the non-significant differences in TTAU duration under time pressure and under no time pressure, whilst ST processing, on the other hand, is very flexible, as STAUs are of significantly shorter duration under time pressure than under no time pressure. With respect to ST comprehension under time pressure, it is a possible explanation that meaning hypotheses are arrived at more quickly; this could have a negative impact on TT quality. The uniformity of TTAU duration could be explained by the fact that the subprocesses involved in TT reformulation and TT typing are not affected by time pressure as they will always occur at the same general speeds. The possible effects of typing on TTAU duration was discussed in section 6.2.4 in relation to Group differences. It is possible that the uniform TTAU durations here is an effect of similar typing patterns under both time conditions, which entails that typing speeds and pause durations between typing events would be the same under time pressure. Although the present study does not control for typing speeds and pause duration, it is nevertheless suggested here again that TTAU duration is likely to be subject to not only typing skills but also to cognitive prioritisation, so that the relatively shorter TTAUs are the result of poor management of cognitive resources and poor typing skills.

6.2.7 PAU duration

Hypothesis **H5b** predicted that PAUs are of shorter duration than both STAUs and TTAUs. In section 6.2.3, post-hoc comparisons were used to examine if there was statistical support for this claim. Post-hoc comparisons between [Attention*Parallel*] and [Attention*TT*] ($t = -53.37$, $p < 0.0001$) and between [Attention*Parallel*] and [Attention*ST*] ($t = -24.83$, $p < 0.0001$) showed that PAUs were significantly shorter than STAUs and TTAUs; the t-values indicated that the differences were indeed very large. In addition, the means considered in relation to other factors also indicated that PAU duration was considerably lower than STAU and TTAU duration. Based on these two circumstances, hypothesis H5b was considered to be confirmed.

Table 6.2f: Mean PAU duration across Group, TextComplexity and TimeConstraint[32]

Group	**Professionals**	**Students**	
	435 ms	419 ms	
TextComplexity	**TextA**	**TextB**	**TextC**
	433 ms	423 ms	430 ms
TimeConstraint	**TimeConstraintNone**	**TimeConstraint100**	**TimeConstraint85**
	423 ms	435 ms	428 ms

The means, illustrated in Table 6.2f above, show very little variation, which could indicate that PAU duration did not differ significantly between subsets of data. In order to investigate this interesting observation inferentially, an LMER model was fitted, which was similar to the one reported in section 6.2.2 above. The model (cf. Table 6.2g) only considered factor level PAU of AttentionType, while factor levels STAU and TTAU of course were not relevant here. All other levels of Group, TextComplexity and TimeConstraint were retained. The PAU data set thus consisted of 4,663 PAU data points. Following the approach of the overall AU duration LMER model in section 6.2.2, PAU duration was logarithmically transformed to reduce skewness.

Table 6.2g: Main effects and interaction effects of PAU duration

Effect (AU duration: PAU)	*Df*	*Sum sq*	*Mean sq*	*F value*	*p(t)*	*Sig.*
Group	1	0.3	0.3	0.9981	0.3	
TextComplexity	2	0.1	0.03	0.0856	0.9	
TimeConstraint	2	1.8	0.9	2.6024	0.1	
Group:TextComplexity	2	0.1	0.1	0.1516	0.9	
Group:TimeConstraint	2	0.2	0.1	0.2922	0.7	
TextComplexity:TimeConstraint	4	1.2	0.3	0.8502	0.5	
Group:TextComplexity:TimeConstraint	4	1.0	0.3	0.7357	0.6	

Df2 for all effects was 4645

The LMER model showed no significant main effects, nor were there any significant interactions. This analysis supports the indication by the means that PAUs, unlike STAUs and TTAUs, are completely inflexible with respect to their duration, irrespective of differences in translational expertise, source text difficulty and time pressure.

One possible explanation for these strikingly similar PAU durations of just below half a second has to do with the *storage* limitations of WM. WM is limited by the *number* of items held within WM and by the amount of *time* this information is available for cognitive

[32] Table 6.2f presents single-factor PAU means of Group, TextComplexity and TimeConstraint only, as these single-factor means sufficiently illustrate that PAU duration was overall uniform. PAU means which consider two or more factors are therefore not illustrated in the table.

processing. WM is able to retain around seven items in a readily available state, and these items may be held in WM for up to 18 seconds (see section 3.1.2). It is possible that the similar PAU durations are manifestations of these capacity limitations. It cannot be ignored, however, that a mean PAU duration of just below half a second is much shorter than the time span of 18 seconds during which information may be retained in WM. It is nevertheless possible that the parallel nature of simultaneous ST comprehension and TT reformulation causes so much interference that the duration in which items are held in WM is reduced considerably. As noted in section 3.1.2, inference reduces considerably the duration in which information is held in WM, and since ST comprehension and TT reformulation compete for access to WM during the translation process a great deal of inference is likely to occur. Another explanation for the similar PAU durations, which does not rule out the storage limitation explanation, concerns the *processing* limitations of WM and the cognitive costs involved in attentional control incurred by parallel processing (see section 3.1.4). More specifically, parallel processing can only take place for shorter periods of time because it generally draws heavily on the central executive's limited pool of resources (e.g. Baddeley 2007, Gazzaniga *et al.* 2002: 247-252). During parallel ST/TT processing, the translator has to divide attention between and thus allocate cognitive resources to two separate resource demanding processes: ST comprehension and TT reformulation. The translator does not have sufficient cognitive resources available to sustain both ST comprehension and TT reformulation for longer periods of time.

One problem with both explanations, however, is that some of the mean PAU durations reported in Table 6.2f are well above 400-500 ms, as illustrated by the density plot in Figure 6.2q below. If there was a fixed storage or processing capacity limitation on the ability to engage in simultaneous ST comprehension and TT reformulation, as suggested here, it comes as a surprise that there are any abnormally long PAU durations.

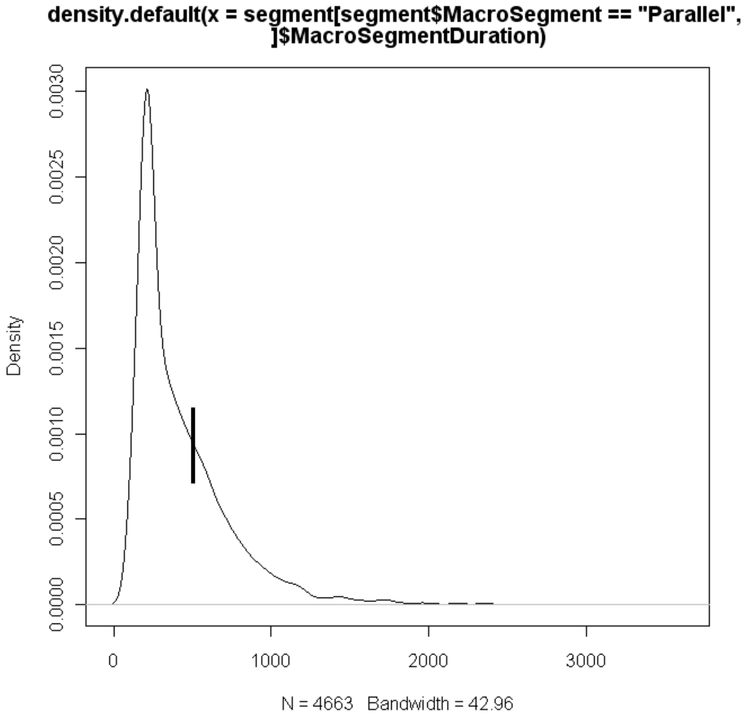

Figure 6.2q: Distribution of PAU data (without logarithmic transformation; the bold line illustrates the mean of the sample (429 ms))

As illustrated by the plot, some PAUs were considerably longer than the overall PAU mean of 429 ms. In order to determine the proportion of 'long' PAUs, a standard deviation (SD) calculation was performed. A 'long' PAU was considered to be one which was longer than one SD above the mean of the PAUs. Around 87 percent of all PAUs were *lower* than one SD above the mean (SD (316 ms) + mean (429 ms) = 745 ms) while 13 percent were *above*. An explanation why 13 percent of the PAUs were 'considerably' longer could be that those PAUs actually were not one single PAU but in fact two or more PAUs which were collapsed into one when AUs were calculated (see section 5.2.3) because they occurred in very close temporal proximity to each other. It is therefore still considered likely that the two explanations of capacity limitation can explain the surprisingly similar PAU durations.

One factor which has not been considered so far in relation to PAU duration is a possible typing effect. The effect of typing on AU duration was already considered in relation to TTAU duration in sections 6.2.4 and 6.2.6, where it was considered possible that TTAU duration was in part affected by typing skills. With respect to PAU duration, it might be that the uniform durations are *not* reflections of limitations on WM but instead reflections of a similar typing pattern for all translators. For instance, it might be that translators need to monitor their typing activities at regular intervals when engaging in parallel ST/TT processing. According to this explanation, the similar PAU durations do not relate to a cognitive limitation but to a specific typing pattern during parallel ST/TT processing, which is shared by all translators. This explanation is nevertheless unlikely since it assumes that typing skills are uniform for all translators under all conditions. For instance, it assumes that touch typing for professional translators translating an easy text under no time pressure would be similar to touch typing for student translators translating a difficult text under heavy time pressure. Although this is not theoretically impossible, it is highly unlikely given that professional translators and student translators generally do not share the same level of touch typing skill. If touch typing skills was a factor which affected PAU duration, PAU duration would be longer for touch typists than for non-touch typists. Also, while it might be reasonable that translators will need to monitor their typing activities throughout the translation process, it is considered highly unlikely that the monitoring activities occur with such regularity that it takes place consistently for *all* translators after around 0.4 seconds. The similar PAU durations are therefore considered to be indication of a limitation on WM rather than an effect of typing.

The findings discussed throughout this section are therefore taken to provide indication that (1) parallel processing occurs in translation (which supports the findings of the analyses in section 6.1.2), (2) parallel processing is subject to either the storage limitations or the processing limitations of WM and that (3) there is an upper parallel processing limit which is uniform for all translators. With respect to the latter two suggestions, the findings to do with WM could be tested in a more controlled setting than in the present in order to confirm this study's findings.

6.2.8 Conclusion on management of cognitive resources

This section investigated the study's second research question **R2**, which asked "*How are cognitive resources managed during translation?*" To answer this question, five hypotheses were examined. With respect to the type of processing, it was found that cognitive resources were allocated to TT processing for longer periods of the time than to ST processing. In other words, translators maintain cognitive resources allocated to TT processing for longer periods of time than to ST processing before switching the allocation of cognitive resources to another task. In this context, one likely explanation is that ST comprehension requires fewer cognitive resources than TT reformulation. Cognitive resources were allocated to parallel ST/TT processing for very short periods of time, which were surprisingly similar in duration (< 0.5 seconds). This indicates that this type of processing is particularly resource demanding as it can only be sustained for brief moments, possibly because there is a limitation on the human memory system to engage in two tasks at the same time. Compared to professional translators, student translators generally maintained cognitive resources allocated to ST processing for longer periods of time; one likely explanation is that it takes more time for less skilled translators to identify ST meaning. Conversely, student translators allocated cognitive resources to TT processing for shorter periods of time, which could indicate that less skilled translators give low priority to reformulation in the TL. Source text difficulty did not have an effect on translators' management of cognitive resources. A likely explanation is that the translators experienced no difference between the texts in terms of their levels of difficulty. Finally, under time pressure, cognitive resources were generally allocated for shorter periods of time to ST processing than under no time pressure. A probable explanation is that ST meaning is identified more quickly as less time is available. TT processing was not affected under time pressure. This means that when a translator translates under time pressure, it is ST comprehension which is affected rather than the amount of time allocated to TT reformulation.

Overall, the results of the analyses show that AUs are very flexible with respect to their durations. Following the assumption that AU duration is an indicator of the translator's management of cognitive resources, the differences in AU duration show that the manner in which translators manage cognitive resources is affected by the type of processing, differences in expertise and to the time conditions under which translation is carried out. In other words, the requirements of a given task affect the translator's management of cognitive resources, as the translator will seek to make the most of her limited cognitive resources.

6.3 Cognitive load

Research question **R3** asked “How does cognitive load vary during translation?”; five single-factor hypotheses which consider cognitive load were formulated to answer this question. The investigation relied on the assumption that changes in pupil size are indicative of changes in cognitive load: higher cognitive load is reflected in larger pupils and lower cognitive load is reflected in smaller pupils. As in the previous sections, calculations of means, linear mixed-effects modelling and post-hoc analysis were used to examine the hypotheses.

Section 6.3.1 presents the statistical model that was used to analyse the pupil size data and it presents the overall results from that analysis. Sections 6.3.2 to 6.3.5 discuss the hypotheses which consider cognitive load in relation to the results from the LMER model and in relation to the relevant post-hoc comparisons. Finally, a conclusion is presented in section 6.3.6.

6.3.1 Statistical methods and effects

An LMER model (see section 5.3 above) was used to analyse changes in the 24 participants’ pupil sizes when they translated the experimental texts. The model included the four extrinsic, intrinsic and implied factors, which were introduced earlier, the random factor participant, and the dependent variable ‘pupil size’ (in mm) (see section 5.2.3.2). The data set consisted of 17,937 pupil size data points. No logarithmic transformation of the dependent variable pupil size was performed as the untransformed distribution appeared to be reasonably symmetrical (cf. Figure 6.3a).

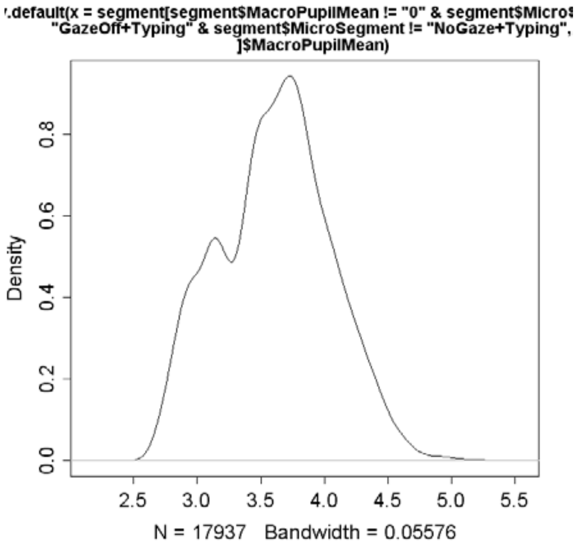

Figure 6.3a: Data distribution without logarithmic transformation (pupil size)

Main and interaction effects of the LMER model are presented in Table 6.3a below. As in the previous LMER analyses, the column *Sig.* gives an interpretation of the significance level for each effect; one asterisk (*) indicates that the effect was significant at or just below the 0.05 level, two asterisks (**) show that the effect was highly significant ($p < 0.01$) and three asterisks (***) indicate that the effect was very highly significant ($p < 0.0001$).

Table 6.3a: Main effects and interaction effects of pupil size

Effect (pupil size)	*Df*	*Sumsq*	*Mean sq*	*F value*	*p(t)*	*Sig*
AttentionType	2	43.8	21.9	671.487	<0.0001	***
Group	1	0.5	0.5	14.5052	0.0001	***
TextComplexity	2	2.4	1.2	37.3162	<0.0001	***
TimeConstraint	2	21.4	10.7	328.543	<0.0001	***
AttentionType:Group	2	2.1	1.0	31.7773	<0.0001	***
AttentionType:TextComplexity	4	0.1	0.03	1.0673	0.4	
AttentionType:TimeConstraint	4	0.1	0.03	0.9304	0.4	
Group:TextComplexity	2	2.9	1.4	44.2334	<0.0001	***
Group:TimeConstraint	2	1.2	0.6	19.1274	<0.0001	***
TextComplexity:TimeConstraint	4	0.6	0.1	4.4147	0.0014	**
AttentionType:Group:TextComplexity	4	0.2	0.05	1.4102	0.2	
AttentionType:Group:TimeConstraint	4	0.5	0.1	4.0939	0.0026	**
AttentionType:TextComplexity:TimeConstraint	8	3.6	0.4	13.7362	<0.0001	***
Group:TextComplexity:TimeConstraint	4	1.5	0.4	11.6643	<0.0001	***
AttentionType:Group:TextComplexity:TimeConstraint	8	2.1	0.3	8.0644	<0.0001	***

Df2 for all effects was 17883

The LMER model showed very highly significant main effects for all factors. In addition, the model revealed four significant two-way interactions, three significant three-way interactions and a significant four-way interaction.

As in the post-hoc analysis in sections 6.1 and 6.2, Bonferroni correction (see section 5.3.3 above) was used here by dividing the standard 0.05 p-level by the total number of post-hoc comparisons (n = 95) that were carried out. Having done so, the new p-level was 0.0005. Any effect in the post-hoc comparisons that had a p-value of more than 0.0005 was considered non-significant. The p-level in the LMER model remained 0.05.

As with the analyses in section 6.2, the present analyses to do with pupil size did not compare factor levels TextB and TimeConstraint100 with other factor levels. As pointed out in section 6.2, the inclusion of these two factor levels would have meant that even more post-hoc comparisons would have had to have been carried out, which would have increased the risk of Type II errors. Also with reference to the problem of the increased risk of Type II errors, post-hoc comparisons between four-factor cells also were not carried out as the number of comparisons would have increased considerably.

6.3.2 Pupil size and AttentionType

This section examines hypotheses H9a and H9b. The first hypothesis **H9a** stated that cognitive load is higher during TT processing than during ST processing. The second hypothesis **H9b** stated that cognitive load is higher during parallel ST/TT processing than during ST processing and TT processing. The effect of AttentionType on pupil size was very highly significant ($F = 671.4872$, $p < 0.0001$), which suggests that the differences between ST, TT and parallel ST/TT pupil sizes were significant. The means, illustrated in Figure 6.3b below, showed that pupils were largest during TT processing (3.67 mm) and smallest during ST processing (3.56 mm). During parallel ST/TT processing (3.58 mm), pupil size was slightly larger than during ST processing but smaller than during TT processing.

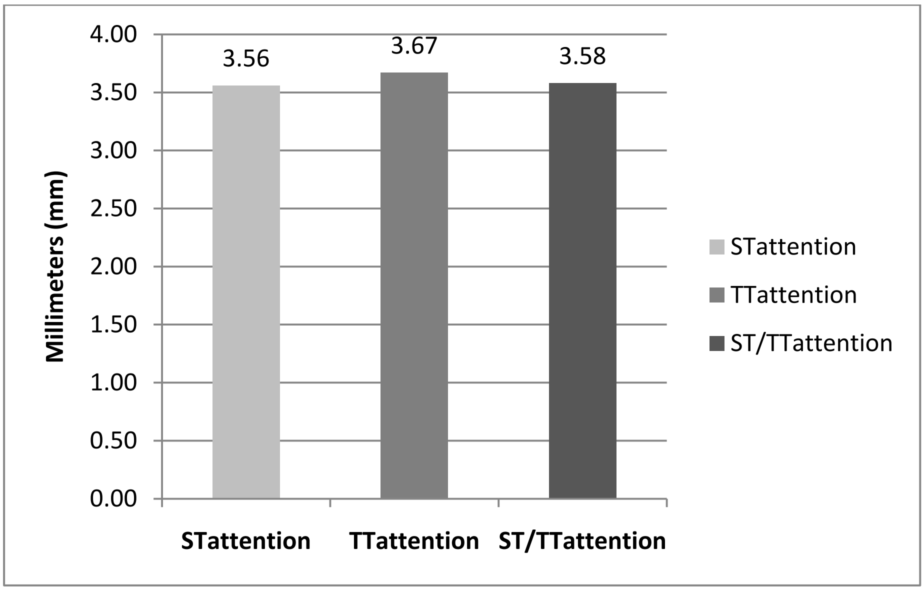

Figure 6.3b: Pupil size: AttentionType

To investigate hypothesis **H9a** more closely, a post-hoc comparison was conducted between [Attention*ST*] and [Attention*TT*]. The comparison revealed that pupils were indeed significantly larger during TT processing than during ST processing ($t = 34.89$, $p < 0.0001$). The significant difference in pupil size so far supports the hypothesis that TT processing incurs higher cognitive load than ST processing. At this point, the hypothesis is confirmed. Based on the discussion of the subprocesses involved in translation in section 3.2, it would appear that ST processing is less cognitively demanding than TT processing, possibly, because lexical and propositional analyses during ST comprehension do not require as many cognitive resources as TT reformulation. The investigation of hypothesis H5a in section 6.2.3 above indicated that the construction of meaning hypotheses is performed more quickly than the recreation of the ST message in the TL; it might therefore further be concluded that ST comprehension is not only performed more quickly than TT reformulation, but ST comprehension is also experienced as an easier subtask of translation than TT reformulation.

In order to investigate in more detail hypothesis **H9b**, two post-hoc comparisons were carried out between [Attention*ST*] and [Attention*Parallel*] and between [Attention*TT*] and [Attention*Parallel*]. The first comparison showed that pupils were significantly larger during parallel ST/TT processing than during ST processing ($t = 20.03$, $p < 0.0001$). The second comparison, which also reached significance, showed that pupils were in fact *smaller* during parallel ST/TT processing than during TT processing ($t = -11.26$, $p < 0.0001$). This hypothesis is so far only partially confirmed as cognitive load is higher for parallel ST/TT processing than for ST processing but lower than for TT processing.

There are several possible reasons for the surprising results of the two post-hoc comparisons. One initial explanation is that the measurement of parallel ST/TT processing does not in fact reflect parallel ST/TT processing but perhaps only ST processing or TT processing; that is, the study's measurements are erroneous. The analysis of PAU duration in section 6.2.7 does not seem to lend support to this explanation, as it found that PAU duration was non-significantly different when considered in relation to Group, TextComplexity and TimeConstraint, i.e. PAU duration remained the same under all conditions investigated in the present study. This observation provides strong indication that the highly systematic uniformity with respect to duration is likely to be linked to WM capacity limitations and less likely to be linked to measurement error.

Another more probable explanation has to do with automaticity. As noted in section 3.1.4, Baddeley's (2007) notion of a central executive system maintains that only one task can be at the centre of attention at any given time. In the case of parallel ST/TT processing, this means that either ST processing or TT processing will be consciously processed by the translator, whilst the process which is not at the centre of attention will occur automatically, demanding few cognitive resources (see also section 3.2.3 on automatic processing in translation). Since automatic processing does not generally occupy many cognitive resources, it is a possible explanation that the surprisingly low cognitive load demonstrated by the translators' pupils is the result of automatic processing during parallel ST/TT processing. For instance, while reading the ST and constructing a meaning hypothesis, the translator is automatically engaged in typing (recall that the discussion in section 3.2.2 established that the central executive is not involved in executing typing events). Similarly, while typing the TT and planning and encoding the TL message, the translator is engaged in ST reading, which is low cognitively demanding in the sense that it, initially, involves only orthographic analysis within sensory memory (see sections 3.1.1 and 3.2.1.1).

AttentionType entered into several significant interactions; it may be that examination of these interactions will provide a better understanding of cognitive load during parallel ST/TT processing as well as of during separate ST processing and TT processing.

Interaction between AttentionType and Group

Above, post-hoc comparisons indicated that hypothesis **H9a** holds. With respect to hypothesis, **H9b**, there was only partial confirmation. Below, the very highly significant two-way interaction between AttentionType and Group ($F = 671.487$, $p < 0.0001$) is examined in relation to these two hypotheses. The relevant means, shown in Figure 6.3c, revealed that the professional translators' pupils were smallest during parallel ST/TT processing (3.33 mm) and largest during TT processing (3.41 mm). The student translators' pupils were smallest during ST processing (3.75 mm) and largest during parallel ST/TT processing (3.93 mm). In other words, the means indicate that parallel ST/TT processing incurs the highest cognitive load of the three types of processing for student translators, while for the professional translators it would seem that it is TT processing which demands the highest cognitive load.

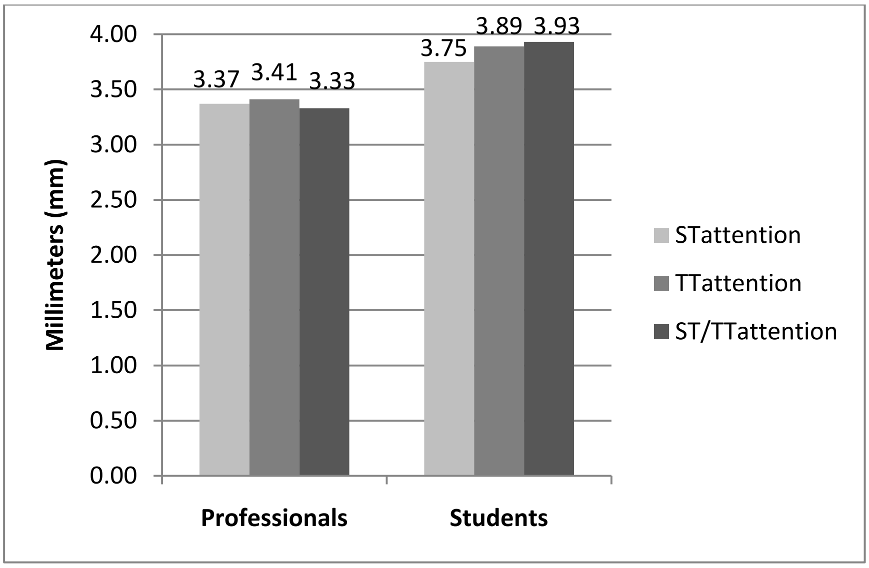

Figure 6.3c: Pupil size: AttentionType and Group

In order to test if the differences indicated by the means are significant in relation to hypothesis **H9a**, two post-hoc comparisons were performed between [Attention*ST*:Group*P*] and [Attention*TT*:Group*P*] (t = 20.93, p < 0.0001) and between [Attention*ST*:Group*S*] and [Attention*TT*:Group*S*] (t = 28.41, p < 0.0001). The significant results of the comparisons indicate that for both professional translators and student translators, TT processing incurs higher cognitive load than does ST processing. The comparison of AttentionType and Group confirms hypothesis H9a so far, as it holds for both professional translators and student translators.

In order to test hypothesis **H9b**, four post-hoc comparisons were conducted. The comparisons were: [Attention*ST*:Group*P*] and [Attention*Parallel*:Group*P*] (t = 9.69, p < 0.0001); [Attention*TT*:Group*P*] and [Attention*Parallel*:Group*P*] (t = -10.47, p < 0.0001); [Attention*ST*:Group*S*] and [Attention*Parallel*:Group*S*] (t = 19.01, p < 0.0001); and [Attention*TT*:Group*S*] and [Attention*Parallel*:Group*S*] (t = -4.51, p < 0.0001). For both groups, all comparisons reached significance. Taking a closer look at the t-values, both professional translators' and student translators' parallel ST/TT processing pupils were larger than during ST processing, but not larger than during TT processing (although the means with respect to student translators indicate differently). These results mirror those found in relation to AttentionType above as they confirm that cognitive load during parallel ST/TT processing is higher during ST processing but not higher during TT processing. Hypothesis H9b is therefore only partially confirmed. The explanation of automaticity proposed above is relevant here also, as both professional translators and student translators engage in automatic processing during parallel ST/TT processing. The question remains, however, whether professional translators and student translators engage in automatic processing to the same extent. The analyses in relation to hypothesis H10 in section 6.3.3 below may be helpful in examining this question more closely.

AttentionType and Group entered into a significant interaction with TimeConstraint. Relevant post-hoc comparisons were carried out below to investigate to what extent TimeConstraint together with AttentionType and Group affected the validity of the hypotheses.

Interaction between AttentionType, Group and TimeConstraint

The interaction between AttentionType, Group and TimeConstraint was highly significant (F = 4.0939, p = 0.0026). The mean pupil sizes (see Figure 6.3d, below) that were relevant with respect to hypothesis **H9a** indicated that both professional translators' and student translators' pupils were larger during TT processing than during ST processing under both time conditions.

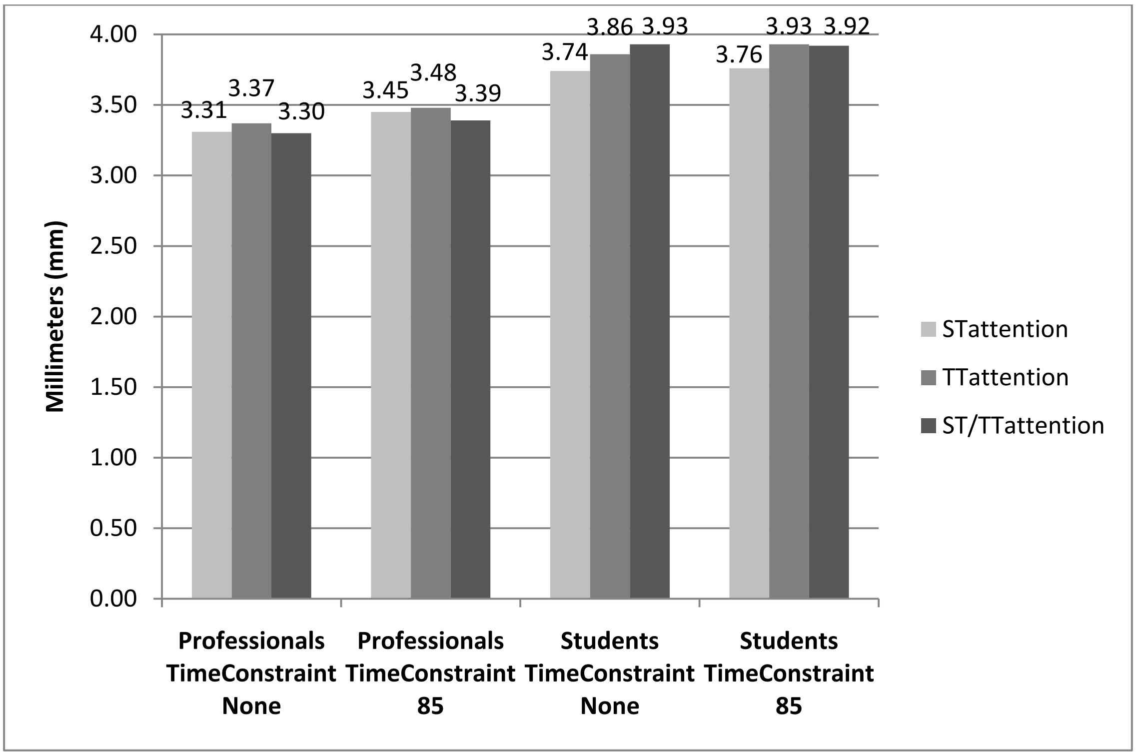

Figure 6.3d: Pupil size: AttentionType, Group and TimeConstraint

To test if the differences indicated by the means were significant in relation to the first hypothesis **H9a**, four post-hoc comparisons were carried out between [Attention*ST*:Group*P*:Time*None*] and [Attention*TT*:Group*P*:Time*None*] (t = 14.34, p < 0.0001); [Attention*ST*:Group*P*:Time*85*] and [Attention*TT*:Group*P*:Time*85*] (t = 9.57 , p < 0.0001); [Attention*ST*:Group*S*:Time*None*] and [Attention*TT*:Group*S*:Time*None*] (t = 17.44, p < 0.0001); and [Attention*ST*:Group*S*:Time*85*] and [Attention*TT*:Group*S*:Time*85*] (t = 16.35, p < 0.0001). All four comparisons were in support of the hypothesis, and they confirmed that pupils during TT processing were larger than during ST processing for both groups under both time conditions. Irrespective of differences in expertise and irrespective of time condition, it still seems that TT processing incurs higher cognitive load than ST processing.

The means that are relevant to hypothesis **H9b** show that under both time conditions, *professional translators*' mean pupil size during parallel ST/TT processing was smaller than during both ST processing and TT processing. For *student translators*, the opposite was observed: mean pupil size during parallel ST/TT processing was larger than during ST processing and TT processing. Eight relevant post-hoc comparisons were carried out to test if the differences between the means were indicative of significant differences. The four comparisons for the professional translators were: [Attention*ST*:Group*P*:Time*None*] and [Attention*Parallel*:Group*P*:Time*None*] (t = 5.57, p < 0.0001); [Attention*TT*:Group*P*:Time*None*] and [Attention*Parallel*:Group*P*:Time*None*] (t = -7.72, p < 0.0001);

[Attention*ST*:Group*P*:Time*85*] and [Attention*Parallel*:Group*P*:Time*85*] (t = 3.48, p = 0.0005); and [Attention*TT*:Group*P*:Time*85*] and [Attention*Parallel*:Group*P*:Time*85*] (t = -6.08, p < 0.0001). The four comparisons for the student translators were: [Attention*ST*:Group*S*:Time*None*] and [Attention*Parallel*:Group*S*:Time*None*] (t = 11.74, p < 0.0001); [Attention*TT*:Group*S*:Time*None*] and [Attention*Parallel*:Group*S*:Time*None*] (t = -2.12, p = 0.0336); [Attention*ST*:Group*S*:Time*85*] and [Attention*Parallel*:Group*S*:Time*85*] (t = 12.09, p < 0.0001); and [Attention*TT*:Group*S*:Time*85*] and [Attention*Parallel*:Group*S*:Time*85*] (t = -2.12, p = 0.0343).

The four post-hoc comparisons that considered professional translators indicate that parallel ST/TT processing, under both time conditions, incurs higher cognitive load than ST processing and lower cognitive load than TT processing. With respect to the comparisons that considered student translators, cognitive load, under both time conditions, is higher during parallel ST/TT processing than during ST processing; cognitive load is, however, not different between parallel ST/TT processing and TT processing under either of the two time conditions. The results therefore mirror those of the two-way post-hoc comparisons between AttentionType and Group in that cognitive load is not higher during parallel ST/TT processing than during TT processing.

The discrepancies between the means presented in Figure 6.3d and the results of the post-hoc comparisons is another good example of the need to treat data inferentially rather than to rely solely on descriptive statistics (see section 5.3.3).

Interaction between AttentionType, TextComplexity and TimeConstraint

The interaction between AttentionType, TextComplexity and TimeConstraint was very highly significant (F = 13.7362, p < 0.0001). With respect to hypothesis **H9a**, the means reported in Figure 6.3e showed that for both the less complex TextA and the more complex TextC under both time conditions, pupils were larger during TT processing than during ST processing. With respect to hypothesis **H9b**, pupil size during parallel ST/TT processing was only larger than pupil size during ST processing and TT processing for the complex TextC translated under no time constraint. Under all other conditions that considered TextComplexity and TimeConstraint, pupil size during parallel ST/TT processing was not larger than during ST processing or TT processing.

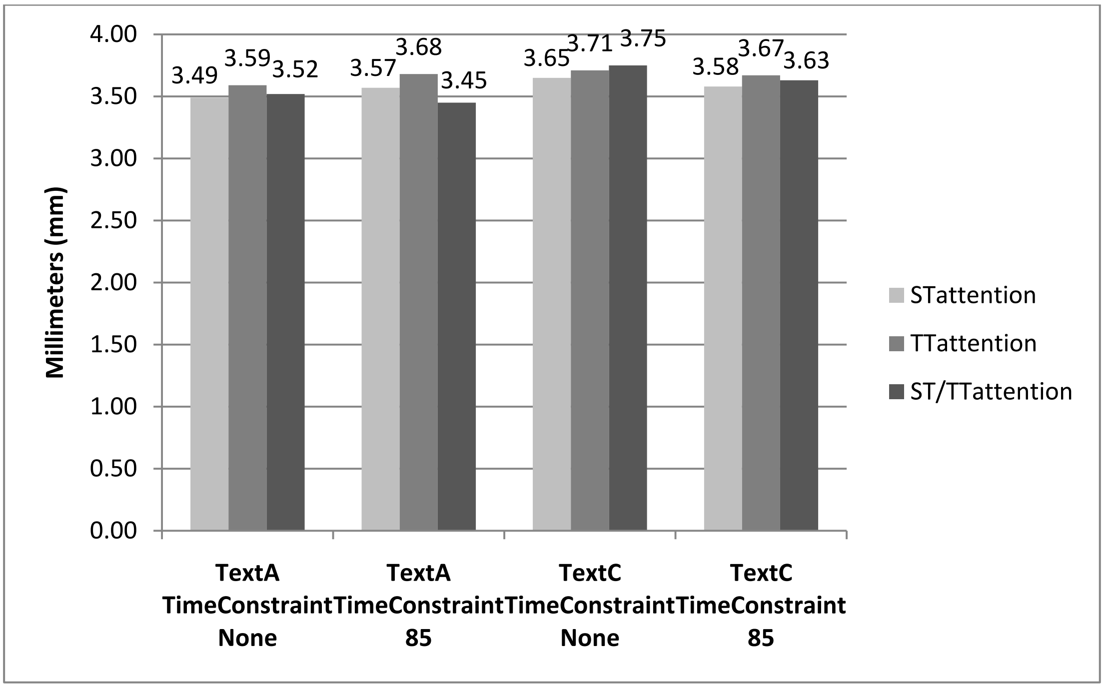

Figure 6.3e: Pupil size: AttentionType, TextComplexity and TimeConstraint

To test hypothesis **H9a** in relation to TextComplexity and TimeConstraint, four post-hoc comparisons were carried out between: [Attention*ST*:Text*A*:Time*None*] and [Attention*TT*:Text*A*:Time*None*] ($t = 14.06$, $p < 0.0001$); [Attention*ST*:Text*C*:Time*None*] and [Attention*TT*:Text*C*:Time*None*] ($t = 15.859$, $p < 0.0001$); [Attention*ST*:Text*A*:Time*85*] and [Attention*TT*:Text*A*:Time*85*] ($t = 7.705$, $p < 0.0001$); and [Attention*ST*:Text*C*:Time*85*] and [Attention*TT*:Text*C*:Time*85*] ($t = 10.295$, $p < 0.0001$). All comparisons revealed that pupils were larger during TT processing than during ST processing under both time conditions and for both texts. Source text complexity did not affect the validity of the hypothesis, as it is still fully confirmed that cognitive load is higher during TT processing than during ST processing.

With respect to hypothesis **H9b**, eight relevant post-hoc comparisons were carried out to investigate differences in pupil size statistically. The four comparisons for no time constraint were: [Attention*ST*:Text*A*:Time*None*] and [Attention*Parallel*:Text*A*:Time*None*] ($t = 6.989$, $p < 0.0001$); [Attention*TT*:Text*A*:Time*None*] and [Attention*Parallel*:Text*A*:Time*None*] ($t = -5.454$, $p < 0.0001$); [Attention*ST*:Text*C*:Time*None*] and [Attention*Parallel*:Text*C*:Time*None*] ($t = 9.130$, $p < 0.0001$); and [Attention*TT*:Text*C*:Time*None*] and [Attention*Parallel*:Text*C*:Time*None*] ($t = -5.079$, $p < 0.0001$). The four comparisons for time constraint were: [Attention*ST*:Text*A*:Time*85*] and [Attention*Parallel*:Text*A*:Time*85*] ($t = 5.056$, $p < 0.0001$); [Attention*TT*:Text*A*:Time*85*] and [Attention*Parallel*:Text*A*:Time*85*] ($t = -2.035$, $p = 0.0418$); [Attention*ST*:Text*C*:Time*85*] and [Attention*Parallel*:Text*C*:Time*85*] ($t = 6.308$, $p < 0.0001$); and [Attention*TT*:Text*C*:Time*85*] and [Attention*Parallel*:Text*C*:Time*85*] ($t = -3.383$, $p = 0.0007$).

The four comparisons, which consider parallel ST/TT processing and ST processing, indicate that cognitive load is higher during parallel ST/TT processing than during ST processing irrespective of text difficulty and time pressure. With respect to the four comparisons which consider parallel ST/TT processing and TT processing, cognitive load during parallel ST/TT processing is either lower than during TT processing (under no time pressure) or not significantly different (under time pressure). The present investigation of the interaction between AttentionType, TextComplexity and TimeConstraint did not provide support for hypothesis H9b other than supporting earlier comparisons which found that parallel ST/TT processing incurs higher cognitive load than ST processing but not higher cognitive load than TT processing.

Summary and discussion (hypothesis H9a)

Hypothesis **H9a** stated that “cognitive load is higher during TT processing than during ST processing”. Table 6.3b provides a summary of this section’s findings:

Table 6.3b: Status of hypothesis H9a

Factor(s) / Status	Attention	Attention:Group	Attention:Group:Time
Confirmation	✓ TT pupils were larger than ST pupils.	✓ TT pupils were larger than ST pupils for both groups.	✓ TT pupils were larger than ST pupils for both groups under both time conditions.
Modifier	*(none)*	*(none)*	*(none)*
Factor(s) / Status			**Attention:Text:Time**
Confirmation			✓ TT pupils were larger than ST pupils for both texts under both time conditions.
Modifier			*(none)*

Pupil size was consistently larger during TT processing than during ST processing in all of the 11 post-hoc comparisons that were carried out. The comparisons therefore supported hypothesis H9a as cognitive load is higher during TT processing than during ST processing. A reasonable explanation for this finding is that language production in translation is comparatively more cognitively demanding than the extraction of information and formulation of meaning hypotheses in language comprehension. Eysenck and Keane’s (2005: 419) claim that ST processing is less cognitively demanding than TT processing is supported again by these observations (see also section 6.1.2 and 6.2.3). In particular, the observations made here also support the findings presented in section 6.2.3 which found that TTAUs were longer in duration than STAUs. There it was speculated that the translator identifies ST meaning relatively more quickly than she identifies a translation equivalent in the TL. Considering AU duration and pupil size in combination, the findings provide indication that TT processing is cognitively more demanding than ST processing both in terms of time consumption but also in terms of the cognitive load placed on the translator's memory system, as indicated by pupil size.

Summary and discussion (hypothesis H9b)

Hypothesis **H9b** stated that "cognitive load is higher during parallel ST/TT processing than during ST processing and TT processing". A summary of the findings from the comparisons is presented in Table 6.3c:

Table 6.3c: Status of hypothesis H9b

Factor(s) / Status	Attention	Attention:Group	Attention:Group:Time
Confirmation	✓ Parallel pupils were larger than ST pupils.	✓ Parallel pupils were larger than ST pupils for both groups.	✓ Parallel pupils were larger than ST pupils for both groups under both time conditions.
Modifier	÷ Parallel pupils were smaller than TT pupils.	÷ Parallel pupils were smaller than TT pupils for both groups.	÷ Parallel pupils were smaller than TT pupils for professionals under both time conditions. - (*Parallel pupils were not significantly larger than TT pupils for students under both time conditions.*)
Factor(s) / Status			**Attention:Text:Time**
Confirmation			✓ Parallel pupils were larger than ST pupils for both texts under both time conditions.
Modifier			÷ Parallel pupils were smaller than TT pupils for both texts translated under no time constraint. - (*Parallel pupils were not significantly larger for either texts translated under time constraint.*)

The 22 post post-hoc comparisons that were carried out to investigate hypothesis H9b provided partial support. The comparisons showed that under all conditions pupil size was larger during parallel ST/TT processing than during ST processing. With respect to TT processing, pupil size during parallel ST/TT processing was either smaller or not significantly different from pupil size during TT processing. Based on this analysis, the hypothesis seems to be only partially confirmed, as TT processing generally incurs higher cognitive load than parallel ST/TT processing, while ST processing is less cognitively demanding than parallel ST/TT processing.

It was considered a likely explanation that either ST processing or TT processing is automated during parallel ST/TT processing. For instance, it may be that the TT processing subprocess of typing executing occurs automatically while cognitive resources are allocated to ST comprehension. As noted in section 3.2.2.3, the execution of typing events does not consume working memory resources; therefore, while the translator is typing, she is simultaneously construing ST meaning. It may also be that during ST reading, the translator is in fact allocating cognitive resources to TT reformulation. This latter proposal challenges Just and Carpenter's (1980) eye-mind assumption, which says that cognitive resources are allocated to the object which is being fixated without appreciable delay. It is not an unlikely challenge, though, as the discussion in section 3.1.1 explained that information is delayed momentarily for around 60 ms in sensory memory before it is forwarded to working memory. During this very brief moment, working memory might well be occupied with TT reformulation instead of cognitively identifying meaning from incoming visual impressions.

The proposal of automaticity nevertheless challenges the proposal of a capacity limitation on parallel ST/TT processing, which was discussed in section 6.2.7, as it seems paradoxical that a cognitively low demanding automatic process, such as orthographic analysis or typing, can prompt these PAUs of surprisingly similar durations. It is, however, not unlikely that the automated processes of ST reading and execution of typing events do in fact place demands on working memory as automated habitual process are monitored to some extent by working memory's attentional controller (see section 3.1.4). There is therefore still basis for hypothesising that there is a capacity limitation on parallel ST/TT processing.

6.3.3 Pupil size and Group

In this section, hypothesis **H10** is investigated. The hypothesis predicted that cognitive load is higher for student translators than for professional translators. The pupil size LMER model showed that the main effect of pupil size and Group was very highly significant ($F = 14.5052$, $p < 0.0001$). The student translators' mean pupil size was greater than the professional translators' (3.85 mm and 3.37 mm, respectively), cf. Figure 6.3f below:

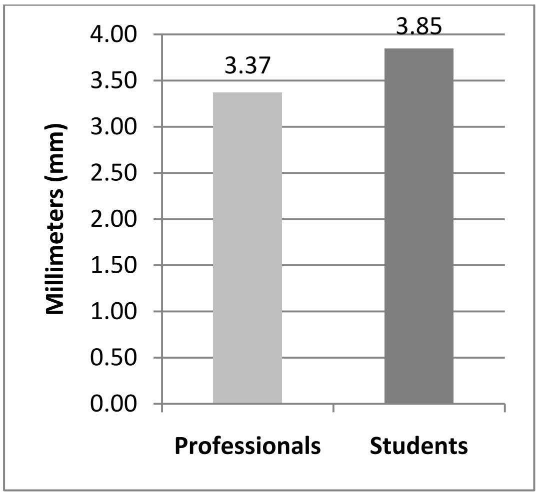

Figure 6.3f: Pupil size: Group

Both the descriptive means and the inferential measure were thus in support of the hypothesis. Since only two levels are included in the LMER main effect above, post-hoc comparison was not necessary. The hypothesis is so far confirmed as cognitive load is higher for student translators than for professional translators. The explanation of automaticity proposed in the previous section is highlighted here again as professional translators, who exhibited lower cognitive load than student translators during translation, rely more on automated processes than do the student translators. Another possible explanation, which does not conflict with the explanation of automaticity but rather supports it, has to do with the cognitive cost involved in attentional switching (see section 3.1.4.3). It is possible that not only attentional switching between ST processing and TT processing, but also attentional switching between lexical and propositional analyses of ST comprehension and planning and encoding of TT reformulation is cognitively more demanding for student translators than for professional translators. In other words, the cognitive cost of switching attention between several tasks is higher for student translators than for professional translators. This latter explanation would have to be examined under more controlled conditions, but the findings of the present study nevertheless provide impetus for such a hypothesis.

Interaction between Group and AttentionType

AttentionType and Group entered into a very highly significant two-way interaction ($F = 671.487$, $p < 0.0001$). For all three types of attention, pupil size appeared to be greater for student translators than for professional translators (see Figure 6.3g).

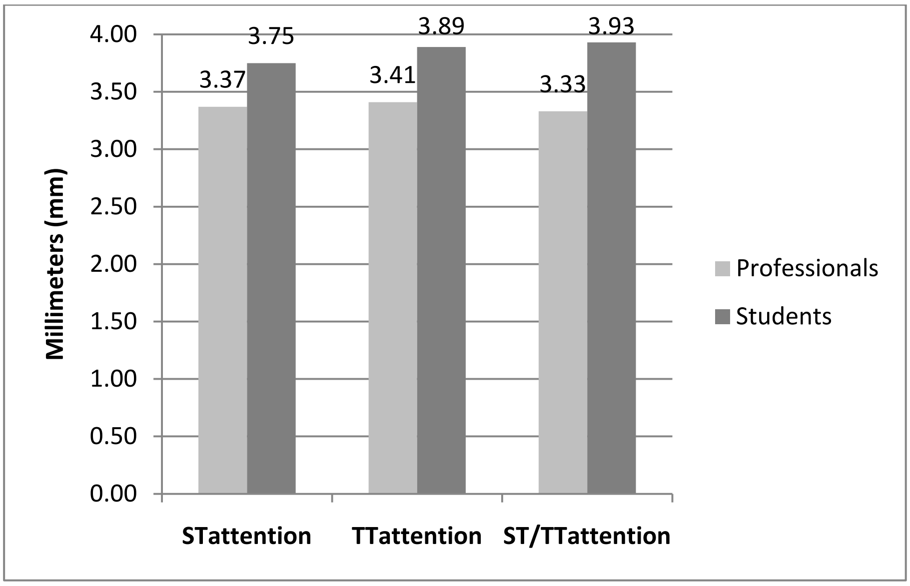

Figure 6.3g: Pupil size: Group and AttentionType

Three post-hoc comparisons were performed to examine if the differences between professional translators and student translators were significant: [Group*P*:Attention*ST*] and [Group*S*:Attention*ST*] (t = 3.61, p = 0.0003); [Group*P*:Attention*TT*] and [Group*S*:Attention*TT*] (t = 3.84, p = 0.0001); and [Group*P*:Attention*Parallel*] and [Group*S*:Attention*Parallel*] (t = 4.04, p = 0.0001). All comparisons were significant, and cognitive load during translation is considered to be higher for student translators than for professional translators, irrespective of the type of processing. Hypothesis **H10** is so far still confirmed by all the relevant comparisons. The confirmation of the hypothesis is not surprising since it was predicted that the task of translating generally draws more on student translators' limited pool of cognitive resources compared to professional translators. However, it is found here that *both* ST comprehension and TT reformulation draw more on the student translators' cognitive resources than on the professional translators' resources. In other words, student translators arguably struggle more than professional translators with both comprehending a source text and producing a translation of it in the TL.

Interaction between Group, AttentionType and TimeConstraint

The interaction between Group, AttentionType and TimeConstraint was highly significant (F = 4.0939, p = 0.0026). The means, illustrated in Figure 6.3h below, all show that professional translators' pupils were smaller than those of student translators' irrespective of the type of processing engaged in by the translators and irrespective of the time conditions under which the translations were carried out.

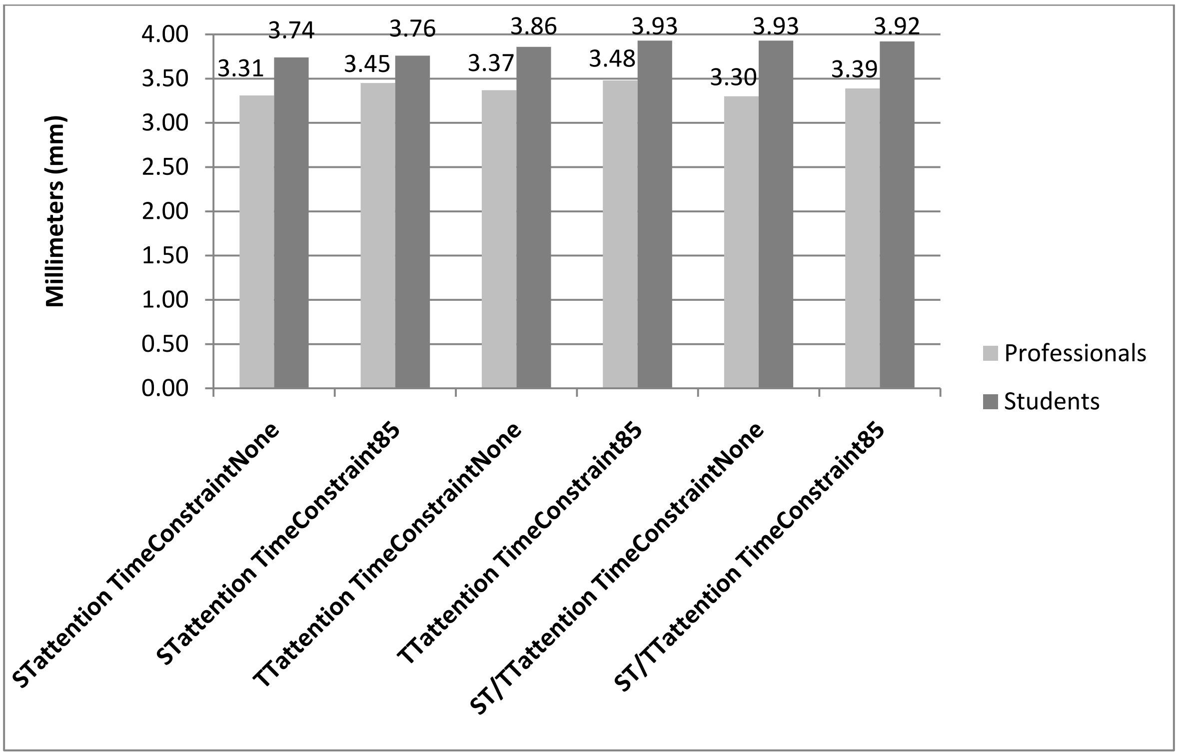

Figure 6.3h: Pupil size: Group, AttentionType and TimeConstraint

In order to test if the differences between the subsets of data were significant, six post-hoc comparisons were conducted. The comparisons were: [Group*P*:Attention*ST*:Time*None*] and [Group*S*:Attention*ST*:Time*None*] (t = 3.66, p = 0.0003); [Group*P*:Attention*ST*:Time*85*] and [Group*S*:Attention*ST*:Time*85*] (t = 3.27, p < 0.0001); [Group*P*:Attention*TT*:Time*None*] and [Group*S*:Attention*TT*:Time*None*] (t = 3.81, p = 0.0001); [Group*P*:Attention*TT*:Time*85*] and [Group*S*:Attention*TT*:Time*85*] (t = 3.69, p = 0.0002); [Group*P*:Attention*Parallel*:Time*None*] and [Group*S*:Attention*Parallel*:Time*None*] (t = 4.12, p < 0.0001); and [Group*P*:Attention*Parallel*:Time*85*] and [Group*S*:Attention*Parallel*:Time*85*] (t = 3.92, p < 0.0001).

The introduction of TimeConstraint did not affect the validity of hypothesis **H10** as all post-hoc comparisons were significant. In other words, under both time conditions, student translators exhibit higher cognitive load than professional translators for all three types of processing. So far, the hypothesis is still fully confirmed by all relevant comparisons as cognitive load is higher for student translators than for professional translators.

Interaction between Group and TextComplexity

The interaction between Group and TextComplexity was very highly significant (F = 44.2334, p < 0.0001). The significant interaction effect suggests that the level of complexity of the source text may have influenced cognitive load for professional translators and student translators during translation. The means (illustrated in Figure 6.3i) show that during translation of the less complex TextA, professional translators' mean pupil size was 3.39 mm and student translators' mean pupil size was 3.87 mm. For the more complex TextC, professional translators' mean pupil size was 3.39 mm while student translators' mean pupil size was 3.86 mm.

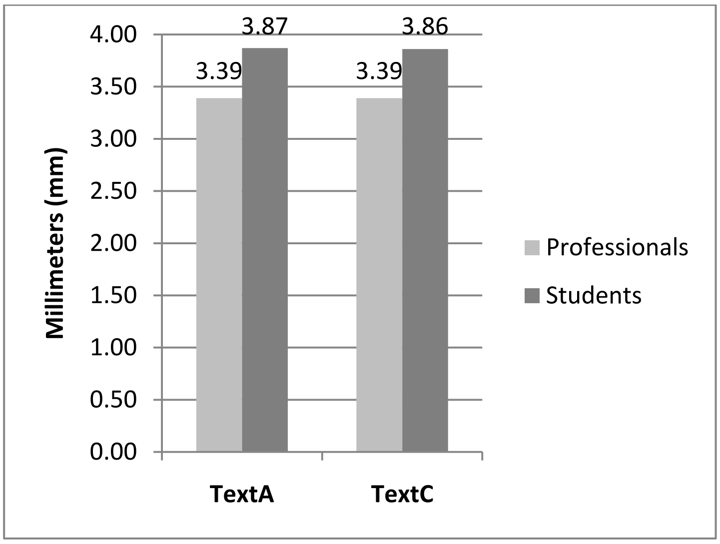

Figure 6.3i: Pupil size: Group and TextComplexity

Two post-hoc comparisons were carried out to test if student translators' pupils were significantly larger than professional translators' for both texts. The comparisons were: [Group*P*:Text*A*] and [Group*S*:Text*A*] and [Group*P*:Text*C*] and [Group*S*:Text*C*]. Both comparisons were significant ($t = 3.88$, $p = 0.0001$ and $t = 3.55$, $p = 0.0004$, respectively), and they confirmed that cognitive load was higher for student translators than for professional translators. Differences in source text complexity did not affect the validity of the hypothesis, and it is so far still fully confirmed.

Group and TextComplexity entered into a significant interaction with TimeConstraint. Below is investigated, the extent to which TimeConstraint affects the validity of the hypothesis.

Interaction between Group, TextComplexity and TimeConstraint

The interaction between Group, TextComplexity and TimeConstraint was very highly significant ($F = 11.6643$, $p < 0.0001$). The means (see Figure 6.3j) show that professional translators' pupils were smaller than student translators' pupils in all comparisons. The differences between the means seemed to be smaller for two of the comparisons, namely for easy text translated under no time pressure and for difficult text translated under time pressure. These small differences could suggest that cognitive load for professional translators and for student translators was more or less the same in these two cases.

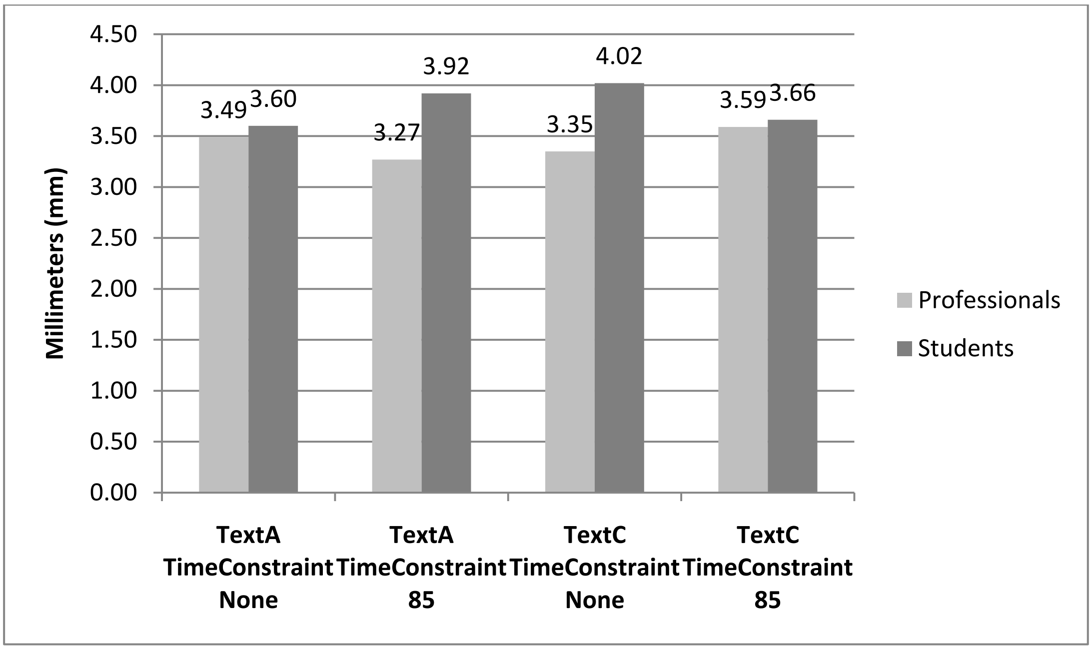

Figure 6.3j: Pupil size: Group, TextComplexity and TimeConstraint

Four post-hoc comparisons were carried out to investigate if the differences in the means were significant. The four comparisons were: [Group*P*:Text*A*:Time*None*] and [Group*S*:Text*A*:Time*None*] ($t = 0.625$, $p = 0.5$); [Group*P*:Text*A*:Time*85*] and [Group*S*:Text*A*:Time*85*] ($t = 2.861$, $p = 0.0042$); [Group*P*:Text*C*:Time*None*] and [Group*S*:Text*C*:Time*None*] ($t = 2.906$, $p = 0.0037$); and [Group*P*:Text*C*:Time*85*] and [Group*S*:Text*C*:Time*85*] ($t = 0.527$, $p = 0.6$). Although the t-values suggest that student translators' pupils were slightly larger than those of professional translators, the non-significant p-values were not able to support the differences in the means.

One initial explanation is that there is in fact no difference in cognitive load between the professional translators and the student translators when considering source text difficulty and time pressure together. This explanation obviously contradicts the findings of the interaction between Group and TextComplexity, above, as well as the findings of the interaction between Group and TimeConstraint, below, which both support the hypothesis. Another more likely explanation is that when TextComplexity and TimeConstraint occur together in the same interaction, the significant effect is obscured. This explanation makes sense assuming that TextComplexity drags the effects on pupil size in one direction while TimeConstraint drags the effects on pupil size in the opposite; the effects of TextComplexity and TimeConstraint thus appear to be neutralised. There is some support for this explanation to be found throughout section 6.3 as almost all the post-hoc comparisons carried out for interactions into which enter both TextComplexity and TimeConstraint are non-significant. The only case in which comparisons were significant was in the interaction between AttentionType, TextComplexity and TimeConstraint in relation to hypotheses H9a and H9b in section 6.3.2 above. Here, it is likely that the differences between pupil sizes during ST processing, TT processing and parallel ST/TT processing were large enough to be captured by the post-hoc comparisons. Since it is likely that effects of TextComplexity and TimeConstraint cancelled out each other, hypothesis **H10** is considered confirmed.

Interaction between Group and TimeConstraint

The final significant interaction into which Group entered was with TimeConstraint; this interaction was very highly significant ($F = 19.1274$, $p < 0.0001$). The means shown in Figure 6.3k suggest that professional translators' pupils were smaller than student translators' across both time conditions, though the difference appeared to be slightly smaller under time constraint.

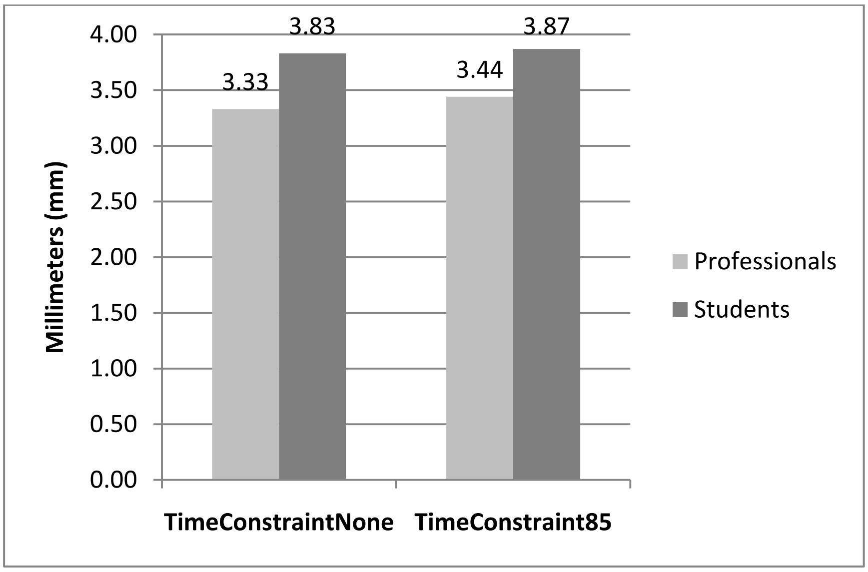

Figure 6.3k: Pupil size: Group and TimeConstraint

Relevant post-hoc comparisons were conducted between [Group*P*:Time*None*] and [Group*S*:Time*None*] and between [Group*P*:Time*85*] and [Group*S*:Time*85*]. Both comparisons reached significance ($t = 3.87$, $p = 0.0001$ and $t = 3.63$, $p = 0.0003$, respectively). The hypothesis is thus still confirmed as student translators exhibit higher cognitive load during translation under both time conditions than do professional translators.

Summary and discussion (hypothesis H10)

To test hypothesis **H10**, 18 relevant post-hoc comparisons were carried out. The hypothesis stated that "cognitive load is higher for student translators than for professional translators". A summary of this section's findings is presented in Table 6.3d:

Table 6.3d: Status of hypothesis H10

Factor(s) / Status	Group	Group:Attention	Group:Attention:Time
Confirmation	✓ Students' pupils were larger than professionals' pupils.	✓ Students' pupils were larger than professionals' pupils for all types of processing.	✓ Students' pupils were larger than professionals' pupils for all types of processing under both time conditions.
Modifier		*(none)*	*(none)*
Factor(s) / Status		**Group:TextComplexity**	**Group:Text:Time**
Confirmation		✓ Students' pupils were larger than professionals' pupils for both texts.	*(none)*
Modifier		*(none)*	- (*For both texts and both time conditions, students' pupils were not significantly larger than professionals' pupils.*)
Factor(s) / Status		**Group:Time**	***Group:Time:Text***
Confirmation		✓ Students' pupils were larger than professionals' pupils under both time conditions.	*(see Group:Text:Time)*
Modifier		*(none)*	*(see Group:Text:Time)*

Student translators' pupils were generally larger than those of the professional translators. Based on the discussion throughout section 6.3.3, hypothesis H10 is considered confirmed, as cognitive load during translation was higher for student translators than for professional translators. Only four post-hoc comparisons were not significant, and it is speculated that the reason for this was that effects of source text difficulty and time pressure are cancelled out when the two factors enter into the same interaction.

Interestingly, cognitive load for student translators is higher than cognitive load for professional translators during *all* three types of processing examined in this study. This means that ST comprehension, TT reformulation as well as parallel ST comprehension and TT reformulation require more cognitive resources for student translators than for professional translators. Two explanations were proposed for the higher cognitive load on the part of the student translators: firstly, professional translators rely to a greater extent than student translators on automatic processing. As established in section 3.2.3, automatic processing does not demand very many processing resources; relying on habitual automatic processing (see section 3.1.4), professional translators are more skilled than student translators at construing ST meaning during translation and identifying TL equivalents of the ST message. Student translators have not developed the same efficient comprehension and reformulation strategies. Secondly, the cognitive cost of switching attention (see section 3.1.4.3), for instance between ST comprehension and TT reformulation, is higher for student translators than it is for professional translators. Put differently, it is less cognitively demanding for professional translators than for student translators to shift attention between translation subtasks. The two explanations do not exclude each other; rather, they support each other as it is likely that both differences with respect to automatic processing and the cognitive cost of switching attention contribute to the differences between professional translators' and student translators' cognitive load in translation.

6.3.4 Pupil size and TextComplexity

This section examines hypothesis **H11**, which predicted that cognitive load is higher when translating a difficult source text than when translating an easy source text. The LMER model showed that the effect of TextComplexity on pupil size was highly significant ($F = 37.3162$, $p = 0.0001$). The pupil size means for each experimental text showed that the translators' pupils were in fact largest during the translation of TextA (3.624 mm), smallest during TextB (3.59 mm), while the pupil size of TextC (3.622 mm) was close to that of TextA, cf. Figure 6.3l.

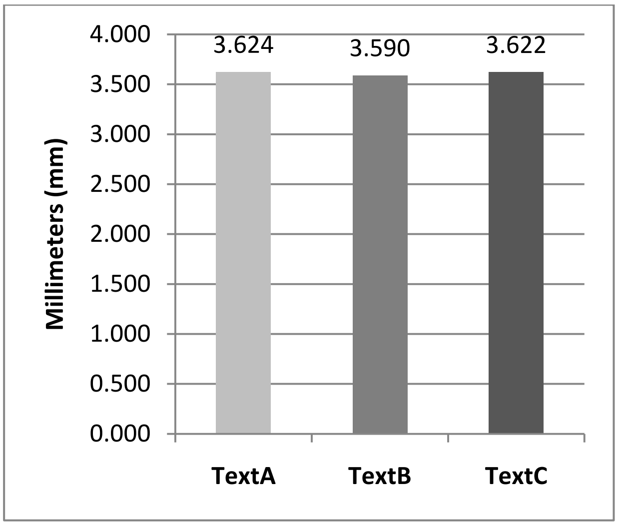

Figure 6.3l: Pupil size: TextComplexity

The means above appear to be surprisingly similar; however, they could disguise variance in the data. To examine if the differences were significant, three post-hoc comparisons were carried out. The first comparison between TextA and TextB ($t = -7.42$, $p = 0.0001$) revealed that pupils were in fact significantly *larger* during translation of TextA than during translation of TextB. This is counterintuitive, as TextB was anticipated to be perceived as more difficult by the translators; here, however, it would seem that the translators experienced TextA as more difficult. The second comparison between TextA and TextC ($t = -1.17$, $p = 0.2$) did not reach significance, and there appears to be no overall difference in pupil size between TextA and TextC. The third comparison between TextB and TextC ($t = 6.48$, $p < 0.0001$) showed that pupils were significantly larger during the translation of TextC than during the translation of TextB. The post-hoc comparisons confirm the indications by the means above: cognitive load is lowest during the translation of TextB, and highest during the translation of TextA and TextC. At this point, the hypothesis cannot be confirmed.

It is interesting that there is no support for hypothesis H11. It was expected that the translation of TextC would have involved significantly higher cognitive load than the translation of TextA. One explanation could be that the participants did not experience any changes in source text difficulty between TextA and TextC, in spite of the fact that TextC, according to the complexity measures described in section 4.3.1, is more complex than TextA. This would strongly suggest that there is no relationship between source text complexity and perceived source text difficulty, at least with respect to the experimental texts used in this study. This explanation was also mentioned in the analyses of TA duration and TextComplexity (in section 6.1.4) and of AU duration and TextComplexity (in section 6.2.5), which also did not find support for their respective hypotheses (H3 and H7).

TextComplexity nevertheless entered into several significant interactions. This could mean that under certain conditions the hypothesis would hold. Below, the hypothesis was investigated in relation to the interactions into which TextComplexity entered. As mentioned in section 6.3.1, TextB was not subjected to further analyses due to the problem of Bonferroni correction. The choice of the text pair TextA and TextC was motivated by the fact that these two texts represented the two extremities on the scale of source text complexity. It was expected that any potential effect would be strongest when comparing this pair rather than a different pair.

Interaction between TextComplexity and Group

The interaction between TextComplexity and Group reached significance ($F = 44.2334$, $p < 0.0001$). The very highly significant interaction effect could suggest that there are significant differences in cognitive load when professional translators' and student translators' pupils were considered separately. Altogether, the differences in the means were very small (see Figure 6.3m).

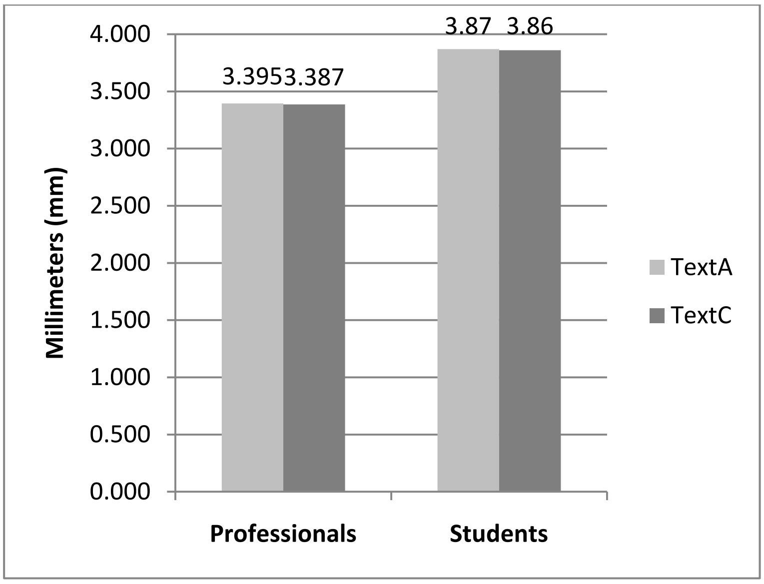

Figure 6.3m: Pupil size: TextComplexity and Group

Two post-hoc comparisons were carried out between [Group$P$:Text$A$] and [Group$P$:Text$C$] and between [Group$S$:Text$A$] and [Group$S$:Text$C$]. The results from the first comparison of the professional translators' pupil size did not reach significance at the Bonferroni-corrected p-level of 0.0005 ($t = 3.35$, $p = 0.0008$). The results from the second comparison of the student translators' pupil size showed that their pupils were in fact significantly larger during translation of the 'easy' TextA than during the translation of the 'difficult' TextC (t = -5.10, p < 0.0001). The analyses therefore indicate that for professional translators, changes in source text complexity do not incur changes in cognitive load. For student translators, there is an effect; however, it is a surprising one since the translation of TextA incurs *higher* cognitive load than the translation of TextC. It seems counter-intuitive that the less complex TextA is experienced as more difficult, as indicated by the large pupil size, than the more complex TextC. An explanation could be that the student translators, for some reason, worked more intensively with the translation of TextA than with the translation of TextC. Perhaps the student translators were so overwhelmed by the difficulty of the translation of TextC that they did not work as thoroughly with its translation as would have normally been needed in order to make a reasonable translation. At this point, there is no support for hypothesis **H11**.

Interaction between TextComplexity, Group and TimeConstraint

The interaction effect between TextComplexity, Group and TimeConstraint was very highly significant (F = 11.6643, p < 0.0001). The relevant means shown in Figure 6.3n indicated no systematic differences in pupil size, other than that the student translators' pupils were generally larger than those of the professional translators.

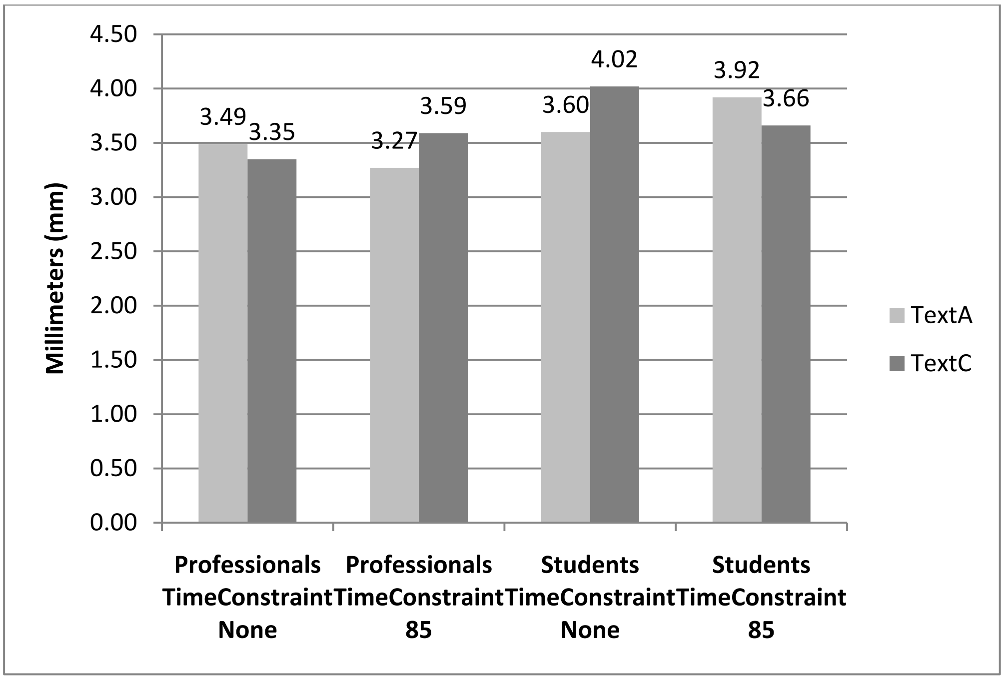

Figure 6.3n: Pupil size: TextComplexity, Group and TimeConstraint

In order to examine if the differences were significant, four post-hoc comparisons were carried out. The comparisons were: [Text*A*:Group*P*:Time*None*] and [Text*C*:Group*P*:Time*None*] (t = -0.728, p = 0.5); [Text*A*:Group*P*:Time*85*] and [Text*C*:Group*P*:Time*85*] (t = 1.274, p = 0.2); [Text*A*:Group*S*:Time*None*] and [Text*C*:Group*S*:Time*None*] (t = 1.553, p = 0.1); and [Text*A*:Group*S*:Time*85*] and [Text*C*:Group*S*:Time*85*] (t = -1.060, p = 0.3).

None of the four comparisons reached significance, in spite of the large differences between the means. The comparisons carried out above did not reveal a significant relationship between TextComplexity, Group and TimeConstraint that can support the hypothesis **H11**, and it is therefore still not considered confirmed. Perhaps, however, it is not surprising that there are no effects, given the explanation proposed in section 6.3.3 that TextComplexity and TimeConstraint cancel out each other when they occur in the same interaction. However, since none of the other comparisons carried out in relation to hypothesis H11 were significant, this explanation is unlikely in this case. It is more likely that there simply was no effect of TextComplexity on pupil size.

Interaction between TextComplexity and TimeConstraint

There was a highly significant interaction between TextComplexity and TimeConstraint (F = 4.4147, p = 0.0014). The means (see Figure 6.3o) show that for both time conditions, pupil size increased with source text complexity. Under no time constraint, pupil size increased from 3.54 mm for TextA to 3.70 mm for TextC. Under time constraint, pupil size increased from 3.58 mm for TextA to 3.62 mm for TextC. There seems to be some indication that the hypothesis can be, at least, partially confirmed.

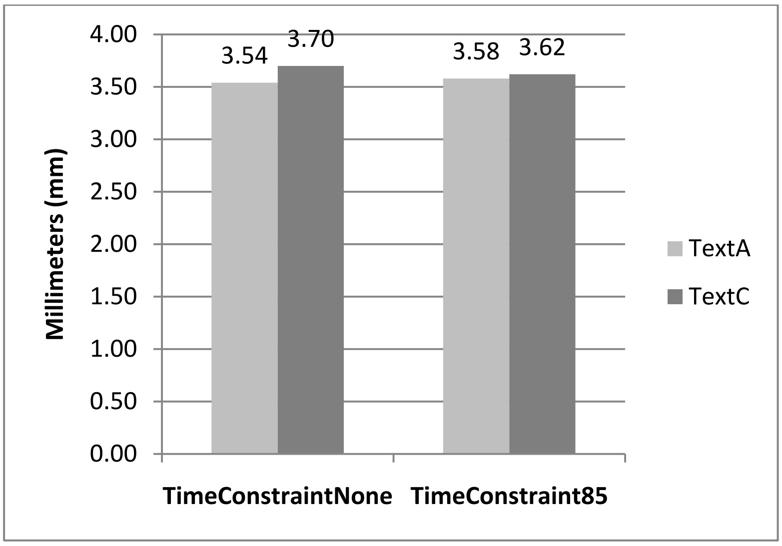

Figure 6.3o: Pupil size: TextComplexity and TimeConstraint

Two post-hoc comparisons were carried out to examine if the differences in the means indicated significant differences: [Text*A*:Time*None*] and [Text*C*:Time*None*] and [Text*A*:Time*85*] and [Text*C*:Time*85*]. The two comparisons did not reach significance (t = 0.439, p = 0.7 and t = 0.121, p = 0.9, respectively), and the validity of hypothesis **H11** still cannot be confirmed.

Interaction between TextComplexity, TimeConstraint and AttentionType

The LMER model showed a very highly significant interaction between TextComplexity, TimeConstraint and AttentionType (F = 11.6643, p < 0.0001). The means that are relevant in relation to hypothesis **H11** show that pupils were larger for TextC than for TextA under both time conditions for all three types of processing, except in one case.

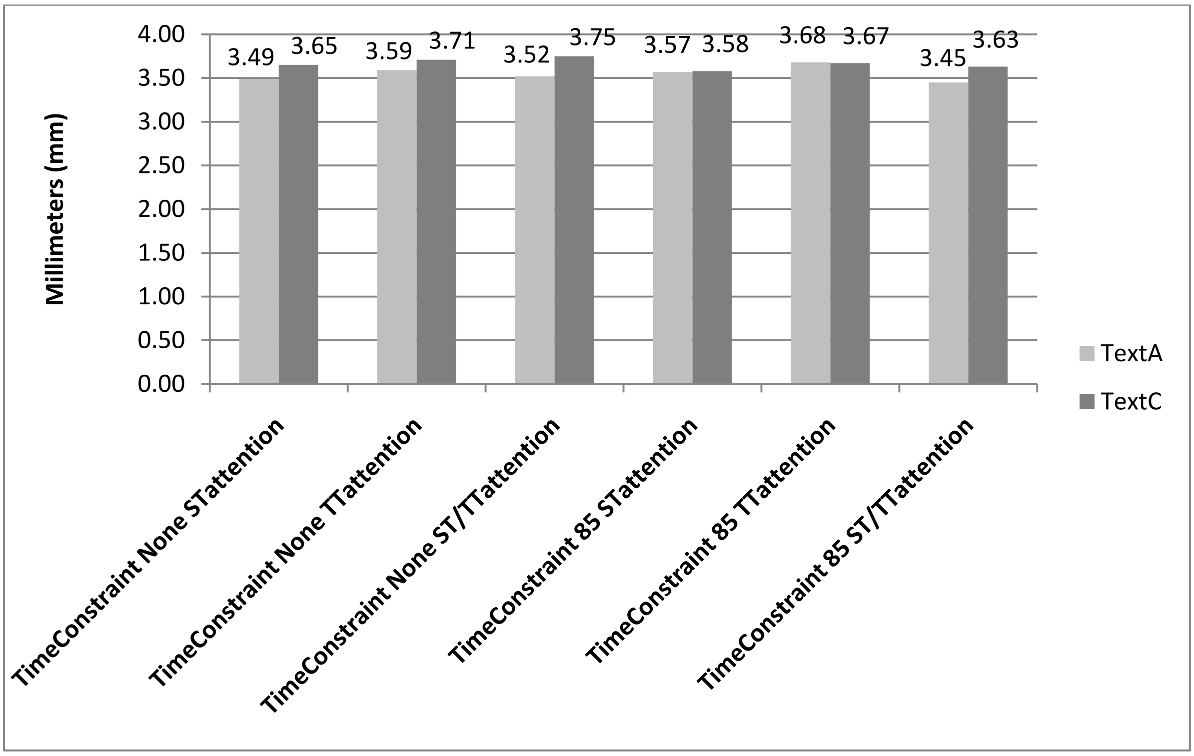

Figure 6.3p: Pupil size: TextComplexity, TimeConstraint and AttentionType

To examine if the differences indicated by the means were significant, six post-hoc comparisons were conducted. The two comparisons for ST processing were: [Text*A*:Time*None*:Attention*ST*] and [Text*C*:Time*None*:Attention*ST*] (t = 0.357, p = 0.7); and [Text*A*:Time*85*:Attention*ST*] and [Text*C*:Time*85*:Attention*ST*] (t = 0.081, p = 0.9). The two comparisons for TT processing were: [Text*A*:Time*None*:Attention*TT*] and [Text*C*:Time*None*:Attention*TT*] (t = 0.431, p = 0.7) and [Text*A*:Time*85*:Attention*TT*] and [Text*C*:Time*85*:Attention*TT*] (t = 0.190, p = 0.9). The two comparisons for parallel ST/TT processing were: [Text*A*:Time*None*:Attention*Parallel*] and [Text*C*:Time*None*:Attention*Parallel*] (t = 0.460, p = 0.6) and [Text*A*:Time*85*:Attention*Parallel*] and [Text*C*:Time*85*:Attention*Parallel*] (t = 0.126, p = 0.9).

None of the six comparisons revealed any significant differences, and they were not able to demonstrate that heavier cognitive load is involved in increased source text difficulty across the two additional factors Group and TimeConstraint. Once again, there is no support for this hypothesis.

Summary and discussion (hypothesis H11)

In Table 6.3e, the results from the 17 post-hoc comparisons that were conducted to examine hypothesis **H11** are summarised. The hypothesis stated that “cognitive load is higher when a difficult source text is translated than when an easy source text is translated”.

Table 6.3e: Status of hypothesis H11

Factor(s) / Status	Text	Text:Group	Text:Group:Time Text:Time:Group
Confirmation	*(none)*	*(none)*	*(none)*
Modifier	- (*Pupils were not significantly larger during translation of complex text than during translation of less complex text.*)	÷ For students, pupils were smaller during translation of complex text than during translation of less complex text. - (*For professionals, pupils were not significantly larger during translation of complex text than during translation of less complex text.*)	- (*For both groups and both time conditions, pupils were not significantly larger during translation of complex text than during translation of less complex text.*)
Factor(s) / Status		**Text:Time**	**Text:Time:Attention**
Confirmation		*(none)*	*(none)*
Modifier		- (*For both time conditions, pupils were not significantly larger during translation of complex text than during translation of less complex text.*)	- (*For both time conditions and for all types of processing, pupils were not significantly larger during translation of complex text than during translation of less complex text.*)

Based on the present data, hypothesis H11 cannot be confirmed as no significant differences could be identified in pupil size and thus cognitive load between texts of varying levels of difficulty. There was only one significant effect, which indicated that cognitive load for student translators translating the complex TextC is in fact *lower* than when translating the less complex TextA.

The study's two other hypotheses to do with TextComplexity (H3 and H7) were also not confirmed. Hypothesis H3 was not confirmed because there were no significant main or interaction effects to support it; it was assumed that the reason for the lack of significance was the limited number of data points (216) available for that analysis. Hypothesis H7 could not be confirmed because there were no significant main effect and two-way interaction effects on which to evaluate the hypothesis. This analysis consisted of 22,947 data points, which made it unlikely that data scarcity was the only problem with the analyses of that hypothesis. An alternative explanation suggested that the translators did not consider the experimental texts different with the respect to their levels of difficulty. This would mean that there is no correlation between the indicators of source text complexity and perceived text difficulty, as TextA and TextC, according to the complexity indicators, were very different with respect to complexity. A third explanation that was mentioned for the non-significant findings with respect to hypothesis H7 was that translators' general experience of source text difficulty does not affect AU duration. While it might be a reasonable explanation with respect to AU duration, this explanation, in relation to pupil size, would challenge the basic assumption that changes in cognitive load correlate with changes in pupil size. It has been demonstrated that changes in cognitive load, i.e. the processing load placed on WM, generally affects the constriction and dilation of the pupil (see section 3.3.1.4). It is therefore a reasonable prediction to make that a more difficult, i.e. cognitively more demanding, source text will impose heavier demands on WM than a less difficult source text. Although this may seem intuitively obvious, it may be that pupil size does not reflect very well changes in cognitive load which are related to differences in source text difficulty. This possibility has in fact been pointed out in other research. Schultheis and Jamesen (2004: 18) found that text difficulty did *not* have an effect on pupil size. Other indicators, such as reading speeds and measurements of EEG[33] did show significant effects of text difficulty in their study. On this basis, it is possible that pupil size in the present study is not a reliable indicator of changes in cognitive load which are caused by differences in source text difficulty. As noted also in section 6.2.5, which concerned source text difficulty and AU duration, the present study would have benefited from qualitative indicators estimating the perceived level of source text difficulty either prior to the experiment or after the experiment. These findings would have been helpful, not only in the process of selecting experimental texts which would have been anticipated to be experienced differently with respect to difficulty, but also in explaining why there were no differences between the texts according to the study's indicators of allocation of cognitive resources.

Due to the relatively inconclusive results of the analyses to do with hypothesis H11, it might be relevant in future studies to compare TextA and Text B or TextB and TextC. The hypothesis might have been confirmed (or partially confirmed) if a different pair of texts had been considered. However, due to the general problem of Bonferroni correction (see section 5.3.3), investigation of more pairs was deemed infeasible in the present study, as an even lower p-level would have compromised the conclusions of the other hypotheses.

[33] EEG (Electroencephalography) is a technique, which is often used to measure electrical activity in the brain that is the result of cognitive events such as thinking.

6.3.5 Pupil size and TimeConstraint

The following section investigates hypothesis **H12**, which stated that cognitive load is higher when translating a text under time pressure than when translating a text under no time constraint. The LMER analysis showed a highly significant effect of TimeConstraint on pupil size (F = 37.3162, p = 0.0001). The means, which are reported in Figure 6.3q, show that pupils were smallest when translating under no time constraint (3.58 mm) and largest when translating under the heaviest time constraint (3.64 mm). The pupil size mean for the moderate time constraint was in between at 3.62 mm.

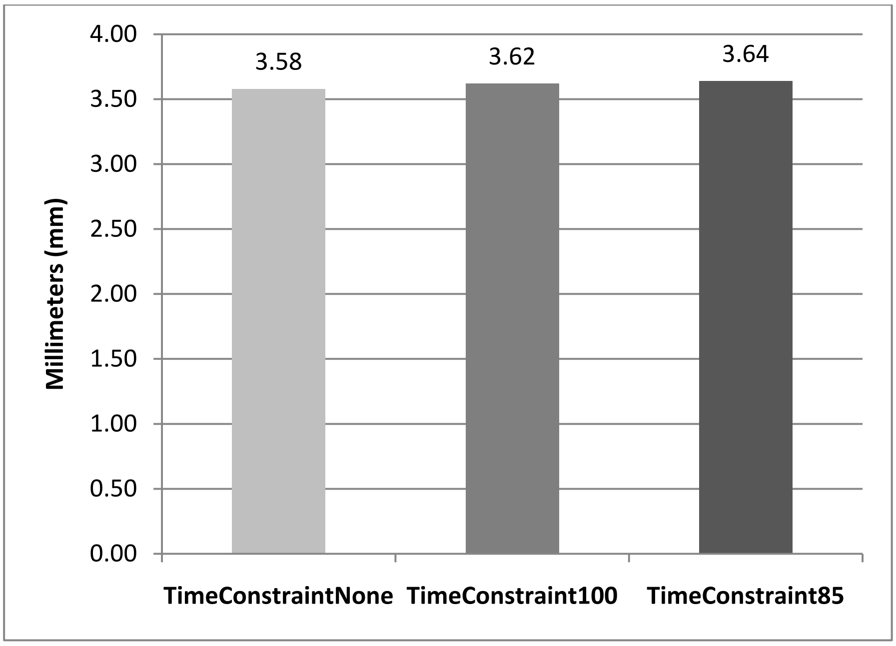

Figure 6.3q: Pupil size: TimeConstraint

The means seem to indicate that pupil size increased with increasing time constraint, as the hypothesis predicted, but in order to investigate if the relatively small differences were significant, three post-hoc comparisons were carried out between [Time*None*] and [Time*100*] (t = 13.86, p < 0.0001) ; [Time*None*] and [Time*85*] (t = 24.84, p < 0.0001); and [Time*100*] and [Time*85*] (t = 10.99, p < 0.0001). The results from the comparisons confirm that pupils were largest when the heaviest time constraint was imposed and smallest when no time constraint was imposed. It follows from the comparisons that higher cognitive load is involved in translation that is carried out under heavy time pressure, while lower cognitive load is involved when the translator works under no time pressure. Hypothesis H12 is therefore confirmed at this point.

The increase in cognitive load under time pressure could be explained by the fact that the same cognitive operations need to be carried out under time pressure as under no time pressure. More specifically, the translator will have to formulate the *same* meaning hypotheses of the ST under time pressure as under no time pressure, and she will *still* have to allocate enough cognitive resources to TT reformulation in order to identify a good translation equivalent. Both of these factors contribute to the workload on working memory, which has to perform more operations in less time.

TimeConstraint entered into several interactions, which must be analysed in order to confirm the validity of the hypothesis. As pointed out in section 6.3.1, the moderate level of time pressure, TimeConstraint100, will not be subjected to further analyses in relation to this hypothesis.

Interaction between TimeConstraint and Group

TimeConstraint entered into a very highly significant interaction with Group ($F = 19.1274$, $p < 0.0001$). The means reported in Figure 6.3r below show that for both professional translators and student translators, pupil size increased when a time constraint was introduced. More specifically, mean pupil size for professional translators working under time constraint was 3.44 mm against 3.33 mm under no time constraint. For student translators, the means were 3.87 mm and 3.83 mm, respectively.

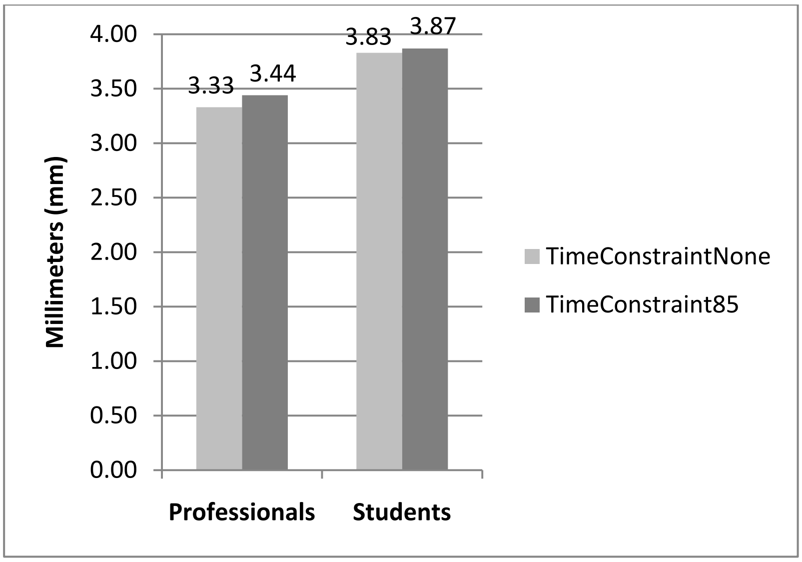

Figure 6.3r: Pupil size: TimeConstraint and Group

In order to test if the differences were significant, two post-hoc comparisons were carried out between [Group*P*:Time*None*] and [Group*P*:Time*85*] and between [Group*S*:Time*None*] and

[GroupS:Time85]. Both comparisons were significant ($t = 20.90$, $p < 0.0001$ and $t = 14.13$, $p < 0.0001$, respectively), and hypothesis **H12** is so far still confirmed as higher cognitive load is registered for translation under time pressure than for translation under no time pressure for both professional translators and student translators.

TimeConstraint and Group entered into two significant three-way interactions, with AttentionType and with TextComplexity, and the validity of the hypothesis may be challenged when taking into account these interactions.

Interaction between TimeConstraint, Group and AttentionType

The interaction between TimeConstraint, Group and AttentionType was highly significant ($F = 4.0939$, $p = 0.0026$). The means reported in Figure 6.3s below indicated that under all conditions investigated in relation to this interaction, pupils were systematically larger under time constraint than under no time constraint with the exception of one. Interestingly, student translators' mean pupil size during parallel ST/TT processing seemed to be slightly smaller under time constraint (3.92 mm) than under no time constraint (3.93 mm).

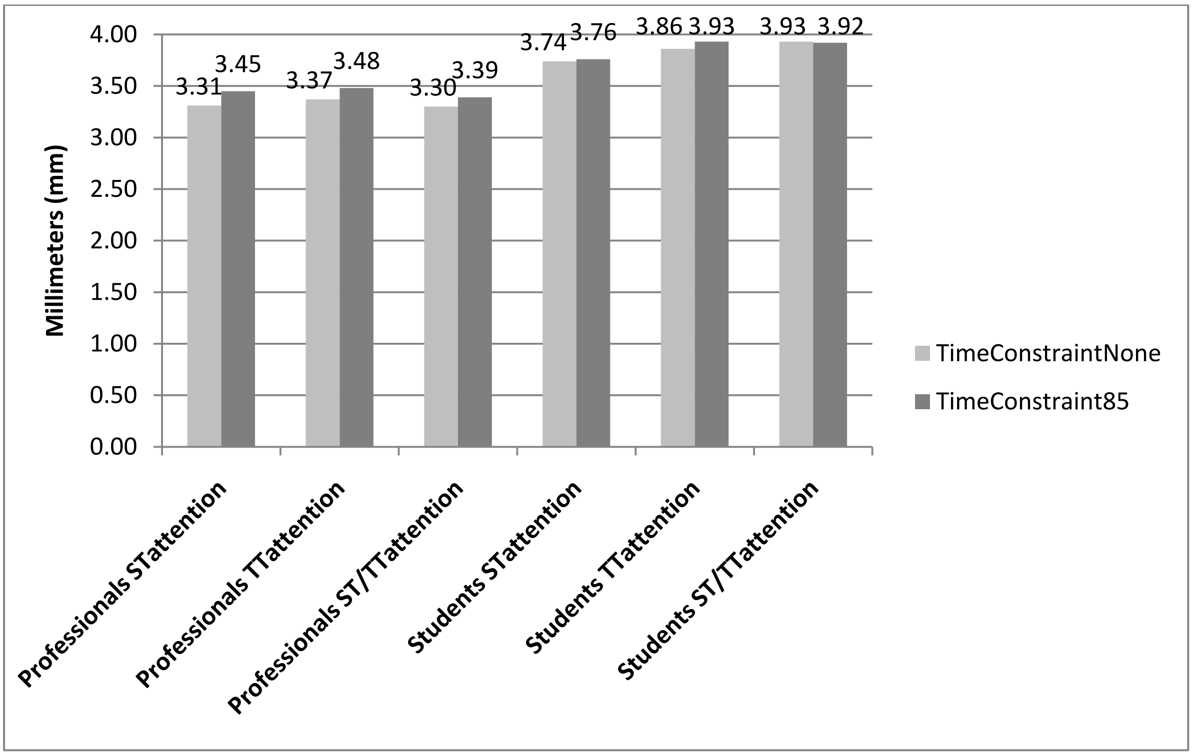

Figure 6.3s: Pupil size: TimeConstraint, Group and AttentionType

Six post-hoc comparisons were conducted to see if the differences reported in the means reached significance. The three comparisons for the professional translators were: [Time*None*:Group*P*:Attention*ST*] and [Time*85*:Group*P*:Attention*ST*] ($t = 14.35$, $p < 0.0001$); [Time*None*:Group*P*:Attention*TT*] and [Time*85*:Group*P*:Attention*TT*] ($t = 11.99$, $p < 0.0001$); and [Time*None*:Group*P*:Attention*Parallel*] and [Time*85*:Group*P*:Attention*Parallel*] ($t = 11.93$, $p < 0.0001$). The three comparisons for the student translators were: [Time*None*:Group*S*:Attention*ST*] and [Time*85*:Group*S*:Attention*ST*] ($t = 8.12$, $p < 0.0001$); [Time*None*:Group*S*:Attention*TT*] and [Time*85*:Group*S*:Attention*TT*] ($t = 10.57$, $p < 0.0001$); and [Time*None*:Group*S*:Attention*Parallel*] and [Time*85*:Group*S*:Attention*Parallel*] ($t = 7.32$, $p < 0.0001$).

All comparisons showed that pupils were significantly larger when translators worked under time constraint. Hypothesis **H12** is therefore confirmed by the present comparisons, and cognitive load is higher when translators work under time pressure, irrespective of the translators' level of expertise and the type of processing that is carried out. This interaction is the only significant interaction into which enter both TimeConstraint and AttentionType. It is interesting to note, however, that cognitive load is higher for *all* three types of processing (ST processing, TT processing and parallel ST/TT processing) carried out under time pressure; in other words, higher cognitive load under time pressure is not isolated to one type of processing.

It should be noted again that the difference in the means of the final comparison in Figure 6.3s above (3.93 mm and 3.92 mm) was not reflected in the post-hoc comparison, which showed the opposite as the t-value was positive. However, as the present study relies on the inferential post-hoc comparisons when testing hypotheses, and only uses descriptive means for illustration (see section 5.3.3), the hypothesis is still considered confirmed at this point.

Interaction between TimeConstraint, Group and TextComplexity

The LMER analysis showed a highly significant three-way interaction between TimeConstraint, Group and TextComplexity ($F = 4.6814$, $p = 0.0009$). The relevant means (see Figure 6.3t) show that there were differences in pupil size between translations carried out under no time constraint and translations carried out under time constraint. These differences went in both directions, and, as appears from these numbers, there seems to be no systematic pattern in pupil size differences when Group or TextComplexity are considered together.

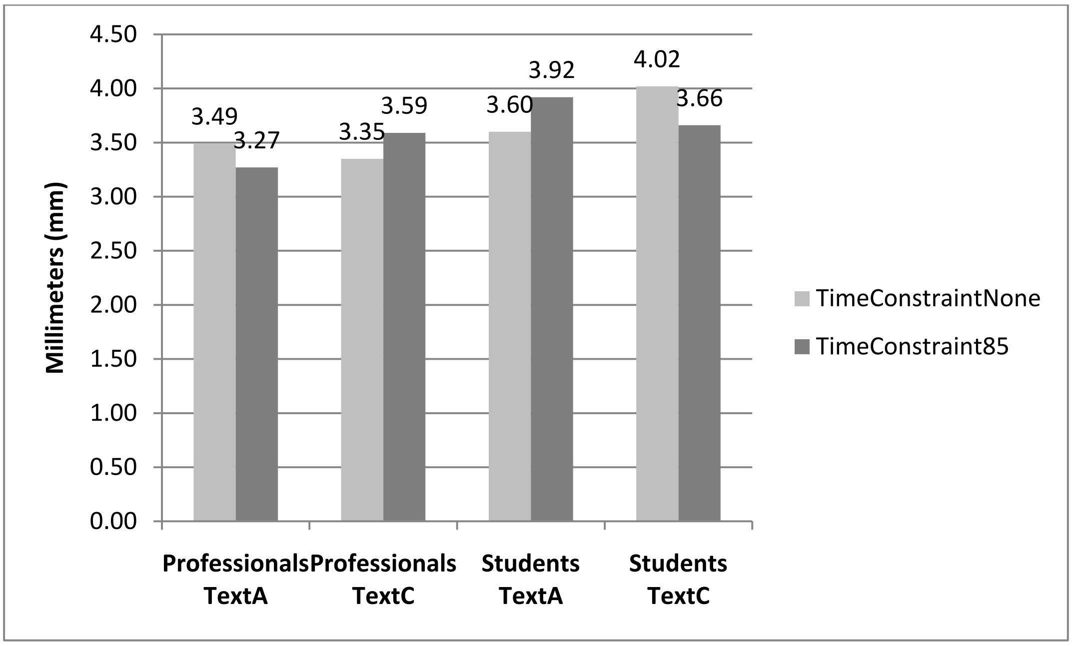

Figure 6.3t: Pupil size: TimeConstraint, Group and TextComplexity

Four post-hoc comparisons were carried out to see if the differences reached significance. The comparisons were: [Time*None*:Group*P*:Text*A*] and [Time*85*:Group*P*:Text*A*] (t = -0.814, p = 0.4); [Time*None*:Group*P*:Text*C*] and [Time*85*:Group*P*:Text*C*] (t = 1.188, p = 0.2); [Time*None*:Group*S*:Text*A*] and [Time*85*:Group*S*:Text*A*] (t = 1.422, p = 0.2); and [Time*None*:Group*S*:Text*C*] and [Time*85*:Group*S*:Text*C*] (t = -1.191, p = 0.2).

None of the comparisons reached significance. Thus, the hypothesis that cognitive load is higher during translation under time pressure than during translation under no time pressure cannot be confirmed when taking into account TextComplexity and Group. One explanation is that time pressure does not affect cognitive load when group differences and differences in source text difficulty are considered together. This explanation nonetheless contradicts the findings of the interaction between Group and TextComplexity, above, as well as the findings of the interaction between Group and TimeConstraint, below, which both support the hypothesis. As proposed also in section 6.3.3 in relation to hypothesis H10, it is considered a very likely explanation that TextComplexity and TimeConstraint together in the same interaction neutralise potential effects as these two factors drag individual effects in opposite directions. Based on this explanation, hypothesis **H12** is considered to be confirmed although the four comparisons carried out here were non-significant.

Interaction between TimeConstraint and TextComplexity

TimeConstraint interacted with TextComplexity. The LMER model showed that the two-way interaction between TimeConstraint and TextComplexity was highly significant ($F = 4.4147$, $p = 0.0014$). The relevant means indicate that for TextA, pupil size was smaller under no time pressure than under time pressure (3.54 mm and 3.58 mm, respectively). For TextC, pupil size was in fact larger under no time pressure than under time pressure (3.70 mm and 3.62 mm, respectively).

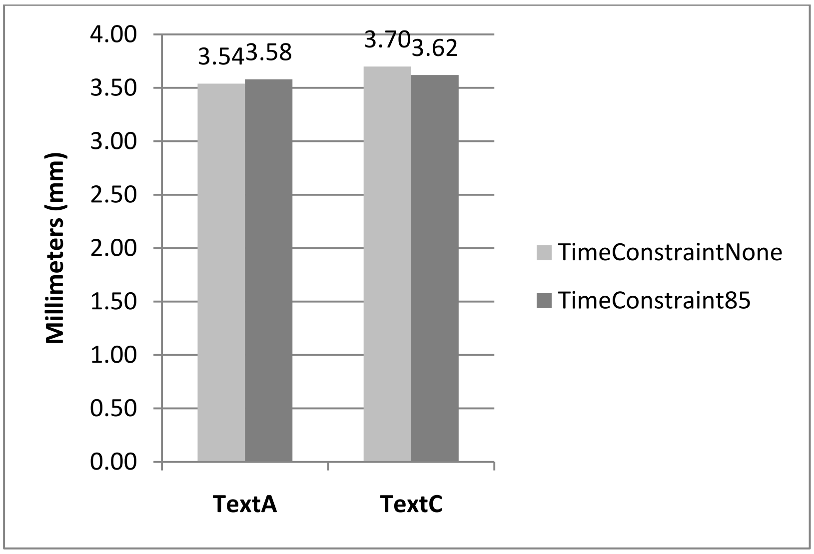

Figure 6.3u: Pupil size: TimeConstraint and TextComplexity

Two post-hoc comparisons were performed to investigate if the differences were significant: [Time*None*:Text*A*] and [Time*85*:Text*A*] and [Time*None*:Text*C*] and [Time*85*:Text*C*]. The comparisons did not reach significance ($t = 0.326$, $p = 0.7$ and $t = 0.009$, $p = 1$, respectively). Hypothesis **H12** cannot be confirmed when TimeConstraint and TextComplexity are considered together in the same two-way interaction; following the explanation stated above, it is probable that TimeConstraint and TextComplexity cancel out each other when they enter into the same interaction.

Interaction between TimeConstraint, TextComplexity and AttentionType

The LMER model revealed a very highly significant three-way interaction between TimeConstraint, TextComplexity and AttentionType ($F = 4.7451$, $p < 0.0001$). Most of the differences in the means interestingly showed that pupils were smaller during translation under time constraint than under no time constraint. This comes as a surprise since pupils were expected to be larger under time constraint than under no time constraint, cf. Figure 6.3v below:

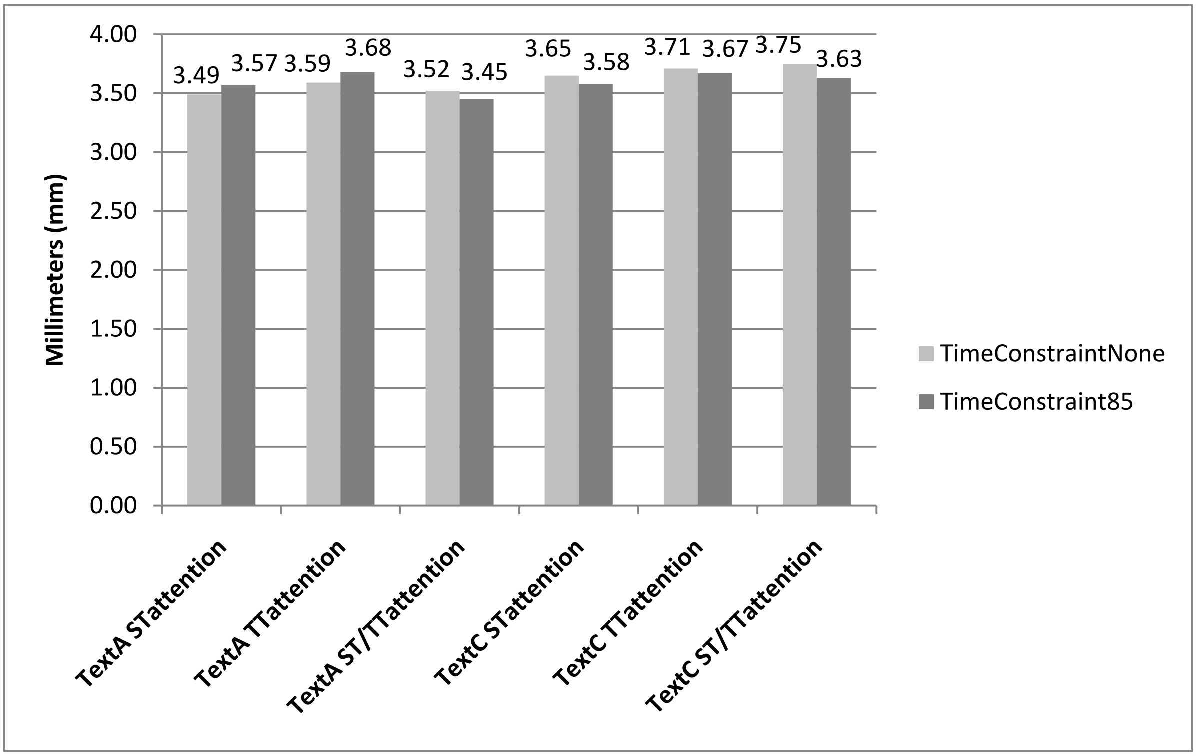

Figure 6.3v: Pupil size: TimeConstraint, TextComplexity and AttentionType

Six post-hoc comparisons were conducted to examine if the differences in the means were significant. The two comparisons for ST processing were: [Time*None*:Text*A*:Attention*ST*] and [Time*85*:Text*A*:Attention*ST*] (t = 0.456, p = 0.6) and [Time*None*:Text*C*:Attention*ST*] and [Time*85*:Text*C*:Attention*ST*] (t = 0.180, p = 1). The two comparisons for TT processing were: [Time*None*:Text*A*:Attention*TT*] and [Time*85*:Text*A*:Attention*TT*] (t = 0.192, p = 0.9) and [Time*None*:Text*C*:Attention*TT*] and [Time*85*:Text*C*:Attention*TT*] (t = -0.049, p = 1). The two comparisons for parallel ST/TT processing were: [Time*None*:Text*A*:Attention*Parallel*] and [Time*85*:Text*A*:Attention*Parallel*] (t = 0.360, p = 0.7) and [Time*None*:Text*C*:Attention*Parallel*] and [Time*85*:Text*C*:Attention*Parallel*] (t = 0.026, p = 1). All comparisons were non-significant, and the hypothesis cannot be confirmed by the comparisons of this particular interaction. Again, the explanation that TimeConstraint and TextComplexity together neutralises potential significant effects by these two factors seems appealing.

Summary and discussion (hypothesis H12)

In order to examine hypothesis **H12**, 23 post-hoc comparisons were carried out. The hypothesis stated that "cognitive load is higher when a text is translated under time pressure than when a text is translated under no time pressure". Table 6.3f presents an overview of the results of this section's analyses:

Table 6.3f: Status of hypothesis H12

Factor(s) / Status	Time	Time:Group	Time:Group:Attention
Confirmation	✓ Pupils were larger under time constraint than under no time constraint.	✓ Pupils were larger under time constraint than under no time constraint for both groups.	✓ Pupils were larger under time constraint than under no time constraint for both groups and for all types of processing.
Modifier		*(none)*	*(none)*
Factor(s) / Status			**Time:Group:Text Time:Text:Group**
Confirmation			*(none)*
Modifier			- (*For both groups and both texts, pupils were not significantly larger under time constraint than under no time constraint.*)
Factor(s) / Status		**Time:Text**	**Time:Text:Attention**
Confirmation		*(none)*	*(none)*
Modifier		- (*For both texts, pupils were not significantly larger under time constraint than under no time constraint.*)	- (*For both texts and for all types of processing, pupils were not significantly larger under time constraint than under no time constraint.*)

The summary shows that hypothesis H12 is confirmed by all post-hoc comparisons carried out which did *not* consider TextComplexity. It was observed that the effects of comparisons that consider both TimeConstraint and TextComplexity are generally non-significant. It was speculated that the effects of TimeConstraint and TextComplexity even out each other, and on this basis the hypothesis is accepted as fully confirmed.

An explanation for the differences in cognitive load is that the same cognitive operations have to be carried out under time pressure as under no time pressure. More specifically, the subprocesses involved in ST processing and TT processing have to be performed more quickly, which draws on the translator's limited pool of cognitive resources which thereby increases cognitive load. Under time pressure the translator still has to comprehend the meaning of the ST well enough to render a meaningful translation in the TL. However, since less time is available, lexical and propositional analyses of ST processing and planning and encoding of TT processing may receive cognitive resources for shorter periods of time. WM therefore has to work more intensively on ST processing and TT processing, which increases cognitive load. A hypothesis to be tested in future studies is that time pressure during translation affects the quality of the TT product negatively since ST comprehension and TT reformulation are likely not to receive sufficient cognitive resources.

6.3.6 Conclusion on cognitive load

The third research question **R3** presented in Chapter 1 asked "*How does cognitive load vary during translation?*" 18,000 data points were used to test five relevant hypotheses. It was found that cognitive load was higher during TT processing than during ST processing, as indicated by larger pupils. An explanation for the higher load is that language production is generally more resource demanding than language comprehension. It was also found that cognitive load during parallel ST/TT processing was only higher than ST processing, and not higher than TT processing. This comes as a surprise, since parallel ST/TT processing was expected to tax quite heavily on the translators' cognitive resources since two tasks are carried out simultaneously; an explanation for the somewhat lower cognitive load has to do with automaticity. More specifically, during parallel ST/TT processing, the translator relies on automatic ST processing or automatic TT processing. With respect to differences in translational expertise, student translators generally exhibited higher cognitive load than professional translators. It is likely that student translators engage in less automatic processing than professional translators and that the cognitive cost of switching the allocation of cognitive resources is higher for student translators than it is for professional translators. Both factors contribute to the higher cognitive load. Source text difficulty did not have an effect on cognitive load. In fact, one analysis showed the opposite as cognitive load for student translators was higher when translating an easy text than when translating a difficulty text. An explanation is that pupil size is not a good indicator of changes in cognitive load which are caused by changes in source text difficulty. Finally, cognitive load was higher during translation under time pressure than under no time pressure. This comes as no surprise, since less time is available under time pressure to carry out the same cognitive operations involved in ST comprehension and TT reformulation.

Although pupil size is not found to be an ideal indicator of changes in cognitive load which relate to source text difficulty, pupil size seems to be a good general indicator of changes in cognitive load with respect to processing type, translational expertise and time pressure. Cognitive load varies considerably throughout the translation process, indicating that the workload which is placed on the translator's memory system is not static. Cognitive load is thus sensitive to the subtask being carried out, the translator's level of expertise and the time conditions under which translation is carried out.

Chapter 7

Conclusion

The overall aim of the present study was to investigate translators' allocation of cognitive resources during the translation process. The study's underlying assumption is that the allocation of cognitive resources varies in different settings. In order to investigate this matter further, three research questions were formulated:

R1 *What is the distribution of cognitive resources during translation?*
R2 *How are cognitive resources managed during translation?*
R3 *How does cognitive load vary during translation?*

A series of translation experiments were carried out in which translation process data from 24 translators were collected using a combination of eye tracking and key logging methodologies. A theoretical framework was built which rested on theories and research from the fields of cognitive psychology, language comprehension, language production and process-oriented translation. Baddeley and Hitch's model of working memory and Baddeley's proposal of attentional control, Kintsch's model of construction-integration during comprehension, Kellogg's model of text production and the theoretical proposals of sequential and parallel coordination of source text (ST) processing and target text (TT) processing in translation were used to (1) identify and qualify the cognitive processes that are involved in translation; (2) identify three indicators of the allocation of cognitive resources (the study's three dependent variables); and (3) formulate the study's hypotheses.

The three dependent variables that were identified were TA duration, reflecting the total amount of cognitive resources allocated to a given process; AU duration, reflecting the translators' management of cognitive resources; and pupil size, reflecting the cognitive load placed on the translators' working memory.

Four factors were considered as potentially having an effect on translators' allocation of cognitive resources. The factors were: (1) different types of processing (comparing ST processing, TT processing and parallel ST/TT processing); (2) variation in translational expertise (comparing professional translators and student translators); (3) differences in source text difficulty (comparing easy text and difficult text); and (4) differences in time pressure (comparing translation under no time pressure and translation under time pressure). These factors constituted the study's four independent variables, and they were considered in each of the study's three analyses as 15 hypotheses were examined. Statistical analyses were carried out using linear mixed-effects modelling. Table 7 summarises the results from the analyses:

Table 7: Overview of hypotheses confirmation

	TA duration	AU duration	Pupil size
AttentionType(a)	H1a: Confirmed	H5a: Confirmed	H9a: Confirmed
AttentionType(b)	H1b: Partially confirmed	H5b: Confirmed	H9b: Partially confirmed
Group	H2: Not confirmed	H6: Partially confirmed	H10: Confirmed
TextComplexity	H3: Not confirmed	H7: Not confirmed	H11: Not confirmed
TimeConstraint	H4: Not confirmed	H8: Partially confirmed	H12: Confirmed

7.1 Distribution of cognitive resources revisited

The first analysis aimed at investigating the first research question concerning *distribution of cognitive resources*. Five hypotheses were formulated, which compared the dependent variable TA duration with one of the four independent variables. The analysis was based on 216 data points.

Hypotheses H1a and H1b had to do with the distribution of cognitive resources to ST processing, TT processing and parallel ST/TT processing. Hypotheses H1a predicted that translators engage more in TT processing than in ST processing. The hypothesis was confirmed as considerably more time was spent on the TT than on the ST. It was concluded that TT reformulation is a cognitively more demanding process than ST comprehension.

Hypothesis H1b predicted that translators engage least in parallel ST/TT processing. This hypothesis was partially confirmed. It was concluded that translators, in general, spend more time on sequential ST processing and TT processing than on parallel ST processing and TT processing. Considering the groups individually, this was confirmed for professional translators but not for student translators. It was speculated that the low number of data points in this analysis could explain the lack of significance. Overall, it was concluded that both parallel processing and sequential processing occurs in translation.

Hypothesis H2 compared how much time professional translators and student translators allocated to translation. It was predicted that student translators would have to spend more time on translation than professional translators. The statistical analysis could not confirm this hypothesis, although the means indicated some differences between the two groups.

Hypothesis H3 investigated how much time translators allocated to the translation of a difficult source text compared to that allocated to the translation of an easy source text. It was anticipated that the translation of a difficult source text would require more time than the translation of an easy source text. Although there were some indications in the means which showed some difference between the texts, this hypothesis was not confirmed by the statistical analysis.

Hypothesis H4 compared how much time was allocated by translators to translation under time pressure and to translation under no time pressure. It was hypothesised that translation under time pressure is, not surprisingly, less time consuming than translation under no time pressure. As was the case with the two previous hypotheses, this one was also not confirmed.

It was considered a general problem of this overall analysis of TA duration that very few data points were available for the statistical analyses. With respect to hypotheses H2, H3 and H4, in particular, it was speculated that the lack of statistical corroboration could be a matter of data scarcity, as the analyses were based on no more than 216 data points.

7.2 Management of cognitive resources revisited

The second analysis aimed at investigating the second research question concerning *management of cognitive resources*. Five hypotheses were formulated that considered the dependent variable AU duration with one of the four independent variables.

Hypothesis H5a compared the duration of STAUs and TTAUs, and it predicted that TTAUs are of longer duration than STAUs. The hypothesis was confirmed as TTAUs were significantly longer than STAUs under practically all circumstances. An explanation was proposed which stated that ST processing is performed more quickly than TT processing because lexical and propositional analyses of ST comprehension are less cognitively demanding than planning and encoding during TT reformulation.

Hypothesis H5b compared the duration of PAUs with those of STAUs and TTAUs. It predicted that PAUs would be shorter than both STAUs and TTAUs. It was not only found that the duration of PAUs was shorter than the durations of STAUs and TTAUs, confirming the hypothesis, but also that PAU duration was surprisingly uniform at around 400-500 ms. An explanation for this latter finding is that there is a capacity limitation on the human memory system's ability to engage simultaneously in ST processing and TT processing. More specifically, parallel ST/TT processing draws heavily on working memory's limited pool of cognitive resources as ST processing and TT processing compete for cognitive resources.

Hypothesis H6 compared the duration of professional translators' AUs with that of student translators. The hypothesis stated that student translators' AUs are of longer duration than professional translators' AUs. The hypothesis was partially confirmed as student translators' STAUs were generally *longer* than professional translators' STAUs, while the student translators' TTAUs were generally *shorter* than those of the professional translators. It was concluded that student translators do not manage cognitive resources optimally as they give too high priority to ST comprehension and too low priority to TT reformulation. The relatively longer STAUs on the part of the student translators were considered likely to reflect the fact the student translators *need* to spend more resources on ST comprehension than professional translators, who, in turn, are able to extract the meaning of the ST more quickly than student translators using efficient comprehension strategies. The relatively shorter TTAUs were proposed to relate the student translators' unawareness of the need to allocate cognitive resources for long enough to arrive at a good rendition of the ST message in the TL.

Hypothesis H7 stated that when translating a difficult source text, translators' AUs are of longer duration than when translating an easy source text. The hypothesis could not be confirmed in the present study. It was suggested that the source texts used in this study, quite surprisingly, did not cause an experience of difficulty although the texts differed considerably with respect to their levels of complexity.

Hypothesis H8 compared the duration of AUs under time pressure and under no time pressure. It predicted that when translating a text under time pressure, translators' AUs are of shorter duration than when translating a text under no time pressure. The hypothesis was confirmed as AUs were generally shorter under time pressure than under no time pressure. It was further found that only *STAUs* were affected by time pressure and not *TTAUs*. It was concluded that TT reformulation is a fairly static process while ST comprehension is the flexible element that is affected during time pressure. A hypothesis which emerged from this analysis was that TT quality would deteriorate under time pressure because of problems relating to comprehension issues rather than to problems relating to reformulation issues. This hypothesis would have to be tested in future experiments.

Most of the factors investigated in the study, apart from source text difficulty, indicated significant differences in AU duration. The findings from the examination of these hypotheses show that translators generally adapt their allocation of cognitive resources quite flexibly in order to meet the requirements of a given task.

7.3 Cognitive load revisited

The third analysis aimed at investigating the research question concerning *cognitive load*. Five hypotheses were formulated, and each compared the dependent variable pupil size with one of the four independent variables. Pupil size was used as an indicator of cognitive load.

Hypotheses H9a predicted that translators' cognitive load is higher during TT processing than during ST processing. It was found that pupils were consistently larger during TT processing than during ST processing, and it was concluded that TT reformulation is more demanding on the human memory system than ST comprehension. In other words, considering the translation process a two-step process, these findings indicate that it is the latter part to do with TT processing that is more demanding on the cognitive system than ST processing.

Hypotheses H9b stated that translators' cognitive load is higher during parallel ST/TT processing than during both ST processing and TT processing. The hypothesis was only partially confirmed as pupils were in fact larger during TT processing than during parallel ST/TT processing. It was concluded that, during parallel ST/TT processing the translator engages in automatic processing so that either ST processing occurs automatically or TT processing occurs automatically. More specifically, processing at the automatic level occurs when (1) the translator reads and comprehends the ST and automatically types TT output, or (2) when the translator reformulates the TT and automatically reads the ST without allocating resources to ST comprehension. The ST reading input is then stored passively in sensory memory for a short moment, after which ST comprehension begins.

Hypothesis H10 investigated differences between professional translators' and student translators' cognitive load. It stated that cognitive load is higher for student translators than for professional translators. The hypothesis was confirmed, and it was concluded that the reason for the professional translators' lower cognitive load had to do with (1) more automatic processing on the part of the professional translators and (2) a lower cognitive cost of switching attention between ST processing and TT processing and between their subprocesses (ST reading, ST comprehension and TT reformulation, TT typing and TT reading, respectively).

Hypothesis H11 compared cognitive load during the translation of difficult text with cognitive load during the translation of easy text, and the hypothesis predicted that when translating a difficult source text, translators' cognitive load is higher than when translating an easy source text. The hypothesis could not be confirmed, as most of the statistical findings were non-significant. Several explanations for the lack of statistical support for the hypothesis were considered and most of them were rejected; however, it was concluded that pupil size is not a reliable indicator of changes in cognitive load which are caused by differences in text difficulty. It was suggested that the study would have benefited from qualitative data to examine if the translators actually considered the translations different with respect to their levels of translation difficulty.

Hypothesis H12 predicted that translators' cognitive load is higher when translating a text under time pressure than when translating a text under no time pressure. The hypothesis was confirmed as pupil size was larger under time pressure than under no time pressure. It was concluded that translation under time pressure involves the same cognitive operations of ST comprehension and TT reformulation as translation under no time pressure. Although less time is available, the translator has to perform the same cognitive operations of language comprehension and language production under time pressure. This intensive processing causes an increase in workload on working memory.

Generally, cognitive load varied considerably under the different conditions under study. The differences were significant on many parameters, apart from source text difficulty, which strongly suggests that pupil size is very useful in determining variation in cognitive load during translation.

7.4 Strengths and limitations of the study

The relatively novel approach of combining eye tracking and key logging was considered a great strength of the study as it provided a more complete picture of the allocation of cognitive resources during the translation process than if only one of these methods had been used. Key logging alone would only have provided indication of TT processing; knowledge about the translator's object of attention during writing pauses would have been inaccessible. Similarly, using eye tracking alone would have been useful only when the translator was looking at the screen; this method would have been unable to provide indication of the translator's object of attention if the translator did not look at the screen. Future studies investigating the cognitive processes of translation are likely to benefit from this combination of two non-intrusive methods. That being said, the present study would have benefited from analyses of data collected with other methods of data elicitation. Retrospective interviews and questionnaire data, for example, would have been helpful in explaining some of the more surprising results. For instance, they could have explained why source text complexity did not appear to have an effect on translators' allocation of cognitive resources. Retrospective data might have revealed that the translators did not experience any difference between the experimental texts with respect to difficulty.

Retrospective data might also have provided a more qualitative account of the translators' perception of time pressure; although the results showed that there were *overall* effects of time pressure, it might be that *some* translators had no experience of time pressure at all. That being said, the methods of eye tracking and key logging generally provide very good indication of what part of the translation the translator is working on, and, for the purpose of this study, they constitute the best approach in terms of completeness for investigating allocation of cognitive resources in translation.

Another methodological strength of the present study is that it proposed an array of indicators to determine the quality of the eye-tracking data: gaze time on the screen, gaze sample to fixation percentage and mean fixation duration. With respect to the latter, earlier translation process studies using eye tracking have often relied on mean fixation duration as an indicator of data quality; the present study found that mean fixation duration does not reliably reflect the quality of the data. When considering the two former parameters, some of the study's translations were excluded because the eye-tracking data quality was extremely poor; these translations would have been included in the study according to the mean fixation duration criterion. The amount of time during which the translator gazes at the screen compared to the total duration of the recording session revealed that some translators, quite surprisingly, only looked at the screen for a couple of seconds, which is obviously too little time to have read the ST. For some translators, the percentage of fixations parameter revealed abnormally large amounts of eye-tracking data that were not classified as fixations. This was considered an indicator that the eye-tracking data are flawed. Had the present study relied on mean fixation duration alone to discriminate good eye-tracking data quality from bad, the results of the analyses would probably have been misleading since they would have been based on data which did not very well reflect the actual object of the translators' attention.

The present study proposed a method of randomising the experimental texts and the experimental time constraints in a manner which reduces the probability that the study's findings are affected negatively by a uniform presentation sequence. It is likely that some of the study's findings would have been less clear if, for instance, all translators had translated the texts in the same sequence, or if all time conditions had been imposed in the same order. Future experiments could also benefit from employing a thorough randomisation design similar to the one proposed in this study.

The results of the source text difficulty analyses were mixed. It was considered a likely explanation that the study's experimental texts did not vary with respect to difficulty as perceived by the translators. The non-significant findings came as a surprise as it was assumed that source text complexity would correlate with source text difficulty. This assumption was based on three source text complexity indicators: readability measurements, word frequency calculations and counts of non-literal expressions, as well as on questionnaire data from native speakers of British English, who confirmed the differences in source text complexity. All four indicators strongly indicated that TextA would be experienced as an easy text, TextB would be perceived as moderately difficult and TextC would be experienced as a difficult text. In spite of what this array of indicators suggested, no correlation was found. The source text complexity analyses of the present study might have benefited either from having more indicators, from indicators that are more reliable or from qualitative tests from pilot experiments carried out prior to the main experiment.

Based on the assumption that translators work at different speeds, the present study used flexible time constraints, and not fixed time constraints, to cause an experience of time pressure on the part of the translator. The study found that translators indeed worked very differently with respect to the speed with which they drafted their translations. It is therefore probable that the results of the analyses concerning time pressure would have been less clear if a fixed experimental time constraint had been used. Future studies that aim at examining the effects of time pressure in translation would benefit from employing flexible time constraints rather than fixed time constraints.

The analyses carried out in the present study were based on data from a rather large number of translators, i.e. 12 professional translators and 12 student translators. Although an empirical study can always benefit from more participants, 24 translators was considered a sufficiently large number of translators to allow the study's findings to be generalised beyond its experiments. In addition to a relatively high number of participants, the analyses to do with *management of cognitive resources* and *cognitive load* were based on a high number of data points (22,947 and 17,937, respectively). Having such a high number of data points allowed the linear mixed-effects models, which were used in this study, to more confidently report if a difference was significant (or not). The benefit of having such a large number of data points is highlighted in the analysis to do with *distribution of cognitive resources*, which found very few significant effects. This analysis was based on 216 data points.

7.5 Future avenues of research

The present study used measures of TA duration, AU duration and pupil size to investigate translators' allocation of cognitive resources in translation. Although a fourth indicator in the present study would have made the statistical analyses even more complicated, it would be interesting in future translation process studies to include measures of fixation duration. For instance, fixation duration, which is a popular measure of cognitive load, might be able to support findings from the pupillometric data and make a study's findings even stronger than if only one cognitive load indicator was used.

It would be interesting to examine if correlation can be found between the allocation of cognitive resources in translation and the quality of a target text. Many of the study's findings could indeed have benefited from supplementary analyses of TT quality in order to examine if there were prototypical patterns of cognitive resource allocation that led to qualitatively better translations. For instance, under the assumption that the two groups of professional translators and student translators behave prototypically with respect to resource allocation, it might be hypothesised that the manner in which professional translators distribute and manage cognitive resources will lead to a better TT translation product. In order to do so, translation process data would have to be compared with TT quality. Such an investigation would be very useful for didactic purposes as it would make possible the identification of the parts of the translation process that require a disproportionate amount of cognitive resources on the part of the translator. An investigation might also be expanded to include bilinguals without translational experience in order to investigate (1) if non-translators allocate cognitive resources differently than translators during translation and (2) if and to what extent the quality of their translation products is connected to their allocation of cognitive resources.

The goal of the study was to examine the *overall* allocation of cognitive resources in translation. The novel approach of combining eye tracking and key logging has proved to be very fruitful in terms of registering with high precision and accuracy when and with what cognitive intensity the translator engages in ST processing, TT processing and parallel ST/TT processing. It would be very interesting to use this methodological approach in future studies to explore cognitive processing at the sentence level or even at the word level.

Dansk resumé

Denne afhandling er en empirisk undersøgelse af oversætteres anvendelse af kognitive ressourcer i oversættelse. Det kognitive system er på mange måder afgørende for den enkelte oversætters unikke processeringsmønster i løbet af oversættelsesprocessen. Selv om ikke to oversættere er ens er der ikke desto mindre forhold, der indebærer, at oversættere deler adfærdsmønstre. Udgangspunktet for afhandlingen er således en forventning om, at oversætteres anvendelse af kognitive ressourcer i nogen grad er forudsigeligt. Tre forskningsspørgsmål blev formuleret til belysning af denne overordnede antagelse:

- Hvad er distributionen af kognitive ressourcer i løbet af oversættelse?
- Hvordan administreres kognitive ressourcer i løbet af oversættelse?
- Hvordan ændres den kognitive belastning i løbet af oversættelse?

I den empiriske undersøgelse tages i betragtning fire faktorer, der tænkes at være medvirkende til oversætteres allokering af kognitive ressourcer: processeringstype (kildesprogsprocessering og målsprogsprocessering), ekspertiseniveau (professionelle oversættere og oversætterstuderende), kildetekstsværhedsgrad og tidspres.

Den empiriske undersøgelse er baseret på teorier inden for flere forskningsfelter. Først og fremmest er undersøgelsen forankret i procesorienteret oversættelsesforskning. Undersøgelsesobjektet i forskning inden for denne gren af oversættelsesforskningen er hovedsageligt de kognitionsprocesser, der knytter sig til udarbejdelsen af oversættelse, og feltet er i en vis grad inspireret af generel kognitionsforskning. I udviklingen af et analyseapparat inddrager afhandlingen også forskning i kognitionspsykologi, idet modeller af arbejdshukommelse, opmærksomhedskontrol, sprogforståelse og sprogproduktion inddrages til at definere en teoriramme, inden for hvilken hypoteser kunne formuleres og evalueres.

Undersøgelsens analyser bygger på data indhentet ved hjælp af en eye tracker, der registrerer øjenbevægelser, og et key logging-program, der registrerer tasteadfærd. Den anvendte metode til dataindsamling adskiller sig fra tidligere undersøgelser inden for procesorienteret oversættelsesforskning idet der er tale om en *kombination* af eye tracking og key logging. Denne kombination af metoder til indsamling af data er medvirkende til, at afhandlingens analyser bygger på data, der i højere grad end ved andre dataindsamlingsmetoder, udgør et mere fuldstændigt billede af oversætteres allokering af kognitive ressourcer i løbet af oversættelsen.

En række oversættelsesforsøg blev gennemført på Copenhagen Business School, hvori deltog 12 professionelle oversættere, der alle var translatører og tolke i engelsk, og 12 oversætterstuderende, der alle læste på cand.ling.merc-studiet med specialeretningen translatør og tolk i engelsk. Forsøgspersonerne oversatte hver tre tekster, der varierede i kompleksitet; to af teksterne blev oversat med en tidsbegrænsning mens en tekst blev oversat uden tidsbegrænsning. Teksterne og tidsbetingelserne blev semirandomiseret for at reducere risikoen for effekter, der opstod som følge af en ensartet præsentationsrækkefølge. Data fra oversætternes oversættelsesprocesser blev behandlet inferentielt ved hjælp af lineære ”mixed-effects” modeller. Disse modeller er særligt velegnet til behandling af undersøgelsens data, idet der tages højde for variation mellem oversættere. Deskriptiv statistik blev anvendt til illustration.

Til måling af ændringer i oversætteres allokering af kognitive ressourcer blev tre indikatorer benyttet: (1) samlet tid (TA duration i sekunder) anvendt på oversættelse, til belysning af oversætteres distribution af kognitive ressourcer; (2) opmærksomhedsenheder (AU duration i millisekunder), til belysning af oversætteres administration af kognitive ressourcer; og (3) pupilstørrelse (i millimeter), til belysning af den kognitive belastning.

Hvad angår det første forskningsspørgsmål, så viste denne delundersøgelse, at oversættere anvendte mere tid på målsprogsprocessering end på kildesprogsprocessering. Denne iagttagelse vedrørte professionelle oversættere såvel som oversættelsesstuderende. Delundersøgelsen fandt også, at målsprogsprocessering og kildesprogsprocessering til tider fandt sted på samme tid. Denne iagttagelse bekræfter teori inden for oversættelse, der forudsiger, at kildesprogsforståelse og målsprogsproduktion finder sted parallelt i oversættelse. Analyserne, der undersøgte forskelle mellem professionelle oversættere og oversættelsesstuderende, mellem kildetekster af forskellige sværhedsgrader og mellem tekster oversat under forskellige grader af tidspres, kunne ikke understøttes inferentielt. Der blev observeret deskriptive forskelle, men ingen kunne altså understøttes af de inferentielle statistiske analyser. Det blev vurderet, at den begrænsede datamængde i denne delundersøgelse var årsag hertil.

For så vidt angår det andet forskningsspørgsmål, så viste delundersøgelsen, at professionelle oversættere allokerer opmærksomhed til målsprogsprocessering i længere perioder end til kildetekstprocessering. For gruppen af oversættelsesstuderende var det omvendt, idet denne gruppe allokerede kognitive ressource til kildetekstprocessering i længere perioder end til målsprogsprocessering. En af årsagerne til denne forskel er, at oversættelsesstuderende er længere om at formulere en meningshypotese. Til gengæld allokerede denne gruppe kognitive ressourcer til målsprogsprocessering i kortere perioder sammenlignet både med kildetekstprocessering og professionelle oversættere. Denne iagttagelse blev tolket som de oversættelsesstuderendes mindre hensigtsmæssige administration af kognitive ressourcer. Delundersøgelsen fandt også, at tidspres påvirker kildesprogsprocessering således, at kognitive ressourcer allokeres i kortere perioder til disse opmærksomhedsenheder. Der blev dog ikke fundet signifikante forskelle i varigheden af de enheder, der afspejler målsprogsprocessering, hvilket tyder på at målsprogsprocessering er en statisk proces, der ikke påvirkes i samme grad som kildesprogsprocessering af processeringstype, ekspertiseniveau, kildetekstsværhedsgrad og tidspres. Delundersøgelsen viste også, at oversættere i almindelighed kun er i stand til at indgå i samtidig målsprogsprocessering og kildesprogsprocessering i ganske korte perioder ad gangen på omkring 0,4 sekunder. Det blev fundet, at denne tidsperiode var ens for alle uanset tekstsværhed og tidspres, og det blev tolket, at en begrænsning på arbejdshukommelsens evne til at processere kildeteksten og målteksten samtidig i længere perioder ad gangen er årsag hertil.

Delundersøgelsen i forbindelse med det tredje forskningsspørgsmål viste, at oversætteres pupiller i alle statistiske sammenligninger var større under målsprogsprocessering end under kildesprogsprocessering. For så vidt angår forskelle mellem professionelle oversættere og oversættelsesstuderende, så allokerede de oversættelsesstuderende flere kognitive ressourcer end de professionelle oversættere til såvel målsprogsprocessering som til kildesprogsprocessering. Årsagen hertil er, at professionelle oversættere i højere grad end studerende processerer automatisk i oversættelse. En anden årsag er, at den kognitive omkostning forbundet med at skifte opmærksomhed mellem oversættelsens kildetekst og måltekst er højere for oversættelsesstuderende end for professionelle oversættere, der er bedre i stand til at effektivisere allokeringen af kognitive ressourcer. Hvad angår sammenligningen mellem tekster, der varierer i kompleksitet som målt ved ordfrekvens, læsbarhed og metafor-, metonym- og idiomindhold, var der ingen signifikante forskelle. Det blev vurderet, at årsagen hertil er, at pupilindikatoren ikke er i stand til at detektere forskelle i kognitiv belastning, som er udløst af forskelle mellem kildeteksters grad af kompleksitet. Analyserne, der sammenlignede pupilstørrelse og tidspres viste, at pupillerne var systematisk større i oversættelse under tidspres end i oversættelse uden tidspres. En forklaring på den øgede kognitive belastning under tidspres er, at de samme kognitive handlinger, der indgår i forståelse og produktion, skal foretages inden for et kortere tidsrum.

Afhandlingens overordnede konklusion er, at oversætteres allokering af kognitive ressourcer er fleksibel idet flere faktorer spiller ind. Først og fremmest belaster kildesprogsforståelse og målsprogsproduktion det kognitive system i forskellig grad, idet målsprogsproduktion kræver flere kognitive ressourcer. Men der er også store forskelle mellem professionelle oversættere og oversættelsesstuderende, som i høj grad allokerer opmærksomhed forskelligt. Professionelle oversættere er i højere grad end oversættelsesstuderende i stand til at optimere allokeringen af kognitive ressourcer.

Tidspres er også en faktor, der spiller ind hos begge grupper af oversættere, idet tidspres vanskeliggør både forståelsesprocessen og produktionsprocessen i form af kortere opmærksomhedsenheder og øget kognitiv belastning. I denne undersøgelse var kildetekstsværhedsgrad ganske overraskende ikke en faktor, der gav sig til udtryk i delundersøgelserne. Det er dog ikke usandsynligt, at en effekt vil kunne registreres, såfremt et andet tekstpar undersøges.

English abstract

This study is an empirical investigation of translators' allocation of cognitive resources, and its specific aim is to identify predictable behaviours and patterns of uniformity in translators' allocation of cognitive resources in translation. The study falls within the process-oriented translation paradigm and within the more general field of cognitive psychology. Based on models of working memory, attentional control, language comprehension and language production, a theoretical framework was developed on which hypotheses were formulated and evaluated. The study's empirical investigation fell into three major analyses, which each dealt with one aspect of translators' allocation of cognitive resources: distribution of cognitive resources, management of cognitive resources and cognitive load. Three indicators were identified: total attention duration (TA duration measured in seconds) indicates the distribution of cognitive resources; attention unit duration (AU duration measured in milliseconds) indicates the amount of time allocated between two attention shifts; and pupil size (measured in millimetres) indicates cognitive load, i.e. workload on working memory.

The empirical investigation used a combination of eye tracking and key logging to collect translation process data from 24 translators. 12 of those translators were professional translators and 12 were student translators. Each translator translated three texts that varied with respect to complexity. Two of these texts were translated under time constraints while one text was translated under no time constraint. These factors were introduced in order to make observations on differences in expertise, differences in source text difficulty, as experienced by the translator, and differences in time pressure, as experienced by the translator. The data were treated inferentially using linear mixed-effects modelling and post-hoc analysis.

With respect to the investigation of TA duration, the study found that more time was spent on target text processing than on source text processing. This observation was made for both professional translators and student translators. The study also found that translators engaged in simultaneous source text processing and target text processing. This latter finding was considered to be in support of the parallel view of the translation process, which holds that translation of a word into the target language occurs without delay.

With respect to the investigation of AU duration, the study found that professional translators focused attention on TT reformulation for longer periods of time than on ST comprehension. For student translators, it was the opposite, as this group focused attention on ST comprehension for longer periods of time than on TT reformulation. One reason for this difference is that student translators need to focus attention on ST comprehension for longer in order to identify ST meaning. In turn, they focus attention on TT reformulation for shorter periods of time – compared to ST comprehension as well as

compared with professional translators. This observation was interpreted as the less than optimal management of cognitive resources on the part of the student translators. Time pressure was also found to have an effect on AU duration as cognitive resources were allocated to ST comprehension for shorter periods of time; interestingly, TT reformulation was not affected significantly by time pressure. The AU duration analysis also indicated that translators in general are able to engage in ST processing and TT processing only for short periods of time (around 0.4 seconds). This time span appeared to be uniform for all translators irrespective of text difficulty and time pressure, and it was interpreted as a limitation of working memory, shared by all translators, to engage in two tasks simultaneously for longer periods of time.

The investigation of pupil size found that pupils were significantly larger during TT reformulation than during ST comprehension in all post-hoc comparisons. Looking at differences between professional translators and student translators, cognitive load was higher for the latter group than for the former during TT processing and ST processing. The explanation is that professional translators rely more on automatic processing than student translators and that the cognitive cost of switching attention between cognitive processes is expected to be heavier for the student translators than for the professional translators, who are more familiar with the task of translating and better at optimally allocating cognitive resources. With respect to source text complexity, the pupil size indicator, somewhat surprisingly, did not detect differences in cognitive load between texts that vary with respect to complexity. An explanation is that the pupil size indicator is not sensitive to registering differences in cognitive load which are related to source text difficulty. The pupil findings to do with time pressure found that pupils were systematically larger under time pressure than under no time pressure. The explanation for the heavier cognitive load is that the translator under time pressure has less time available than under no time pressure to perform the same cognitive operations involved in ST comprehension and TT reformulation. This extra workload on working memory is reflected in larger pupils.

The AU duration and pupil size measures were considered successful in providing insight into translators' allocation of cognitive resources. The TA duration indicator was less successful in revealing significant effects with respect to distribution of resources in translation.

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Appendix A

Participant data

Appendix A1: Professional translators

	Sex	*Education*	*Degree finished*	*Experience* [34]	*State-authorized*
P1	F	MA T&I, English	1995	13 years	Yes
P2	F	MA T&I, English	1974	33 years	Yes
P3	F	MA T&I, English	2000	6 years	Yes
P4	F	MA T&I, English	1989	27 years	Yes
P5	F	MA T&I, English	1978	15 years	Yes
P6	F	MA T&I, English	1999	6 years	Yes
P7	F	MA T&I, English	2005	3 years	Yes
P8	F	MA T&I, English	1981	20 years	Yes
P9	F	MA T&I, English	1979	30 years	Yes
P10	M	MA T&I, English	1976	30 years	Yes
P11	M	MA T&I, English	1996	3 years	Yes
P12	F	MA T&I, English	2005	4 years	Yes
D1	F	MA T&I, English	2006	3 years	Yes
D3	M	MA, English literature	1995	13 years	No

Appendix A2: Student translators

	Sex	*Education*	*Enrolment* [35]	*Experience*
S1	F	MA T&I student, English	2007	< 2 years
S2	F	MA T&I student, English	2007	< 2 years
S3	F	MA T&I student, English	2006	< 2 years
S4	M	MA T&I student, English	2006	< 2 years
S5	F	MA T&I student, English	2004	< 2 years
S6	F	MA T&I student, English	2007	< 2 years
S7	F	MA T&I student, English	2004	< 2 years
S8	F	MA T&I student, English	2007	< 2 years
S9	F	MA T&I student, English	2007	< 2 years
S10	F	MA T&I student, English	2006	< 2 years
S11	F	MA T&I student, English	2007	< 2 years
S12	F	MA T&I student, English	2004	< 2 years
D2	F	MA T&I student, English	2006	< 2 years

[34] Some translators had translation experience from before they finished their degrees.
[35] The master's degree programme in translation is normally taught over two years; however, some student translators in this study have been enrolled for longer (for up to four years).

Appendix B
Experimental texts

(TextA) Killer nurse receives four life sentences

From *The Independent (4 March 2008)*

Hospital nurse Colin Norris was imprisoned for life today for the killing of four of his patients. 32 year old Norris from Glasgow killed the four women in 2002 by giving them large amounts of sleeping medicine. Yesterday, he was found guilty of four counts of murder following a long trial. He was given four life sentences, one for each of the killings. He will have to serve at least 30 years. Police officer Chris Gregg said that Norris had been acting strangely around the hospital. Only the awareness of other hospital staff put a stop to him and to the killings. The police have learned that the motive for the killings was that Norris disliked working with old people. All of his victims were old weak women with heart problems. All of them could be considered a burden to hospital staff.

Number of characters with spaces: 837

Length of headline in characters with spaces: 41

Words (including headline): 148

(TextB) Families hit with increase in cost of living

From *Daily Telegraph (12 February 2008)*

British families have to cough up an extra £1,300 a year as food and fuel prices soar at their fastest rate in 17 years. Prices in supermarkets have climbed at an alarming rate over the past year. Analysts have warned that prices will increase further still, making it hard for the Bank of England to cut interest rates as it struggles to keep inflation and the economy under control. To make matters worse, escalating prices are racing ahead of salary increases, especially those of nurses and other healthcare professionals, who have suffered from the government’s insistence that those in the public sector have to receive below-inflation salary increases. In addition to fuel and food, electricity bills are also soaring. Five out of the six largest suppliers have increased their customers' bills.

Number of characters with spaces: 846

Length of headline in characters with spaces: 44

Words (including headline): 139

(TextC) Spielberg shows Beijing red card over Darfur

From *The Times (13 February 2008)*

In a gesture sure to rattle the Chinese Government, Steven Spielberg pulled out of the Beijing Olympics to protest against China's backing for Sudan's policy in Darfur. His withdrawal comes in the wake of fighting flaring up again in Darfur and is set to embarrass China, which has sought to halt the negative fallout from having close ties to the Sudanese government. China, which has extensive investments in the Sudanese oil industry, maintains close links with the Government, which includes one minister charged with crimes against humanity by the International Criminal Court in The Hague. Although emphasizing that Khartoum bears the bulk of the responsibility for these ongoing atrocities, Spielberg maintains that the international community, and particularly China, should do more to end the suffering.

Number of characters with spaces: 856

Length of headline in characters with spaces: 44

Words (including headline): 132

Appendix C
Panellists questionnaires

Panellist 1

	Comprehensibility	*Coherence*	*Grammatical correctness*	*Difficulty*[36]
TextA	4	2	4	1
TextB	5	5	5	2
TextC	5	5	5	3

Panellist 2

	Comprehensibility	*Coherence*	*Grammatical correctness*	*Difficulty*
TextA	5	5	3	1
TextB	5	5	3	2
TextC	5	5	4	3

Panellist 3

	Comprehensibility	*Coherence*	*Grammatical correctness*	*Difficulty*
TextA	5	5	5	1
TextB	5	5	5	2
TextC	5	5	5	3

Average of all panellists

	Comprehensibility	*Coherence*	*Grammatical correctness*	*Difficulty*
TextA	4.7	4	4	1
TextB	5	5	4.3	2
TextC	5	5	4.7	3

[36] 1 = ‘easiest’, 3 = ‘most difficult’

Appendix D

Quality of eye-tracking data

Appendix D1: Gaze time on screen (GTS) (as a percentage of total production time)

	TextA	*TextB*	*TextC*
P1	82.4	79.0	80.8
P2	72.3	67.8	70.1
P3	69.3	72.3	64.5
P4	29.1	30.6	29.4
P5	69.0	67.1	64.5
P6	36.1	31.9	41.2
P7	71.8	75.0	73.0
P8	86.9	74.4	84.1
P9	75.2	75.3	78.5
P10	37.3	41.2	43.8
P11	89.1	85.2	84.1
P12	85.5	85.4	83.8
S1	49.5	47.4	49.2
S2	28.1	32.8	37.6
S3	63.4	63.1	71.6
S4	73.1	77.5	68.3
S5	42.3	49.6	45.5
S6	38.1	44.1	47.5
S7	77.0	79.0	78.4
S8	58.2	69.3	63.7
S9	72.7	66.2	78.2
S10	43.4	39.5	34.8
S11	38.2	39.4	43.9
S12	34.6	32.3	38.3
D1	0.9	1.4	1.7
D2	9.1	85.6	1.1
D3	21.5	47.5	38.0

Appendix D2: Gaze sample to fixation percentage (GFP)

	TextA	*TextB*	*TextC*
P1	90.92	87.86	88.19
P2	82.42	82.62	81.65
P3	82.45	85.64	80.86
P4	78.01	77.53	81.03
P5	79.64	81.22	74.06
P6	84.02	81.64	81.54
P7	88.73	89.59	87.96
P8	93.72	87	90.82
P9	88.7	88.9	90.54
P10	77.99	80.15	76.57
P11	94.9	93.91	90.95
P12	95.78	95.62	94.73
S1	91.4	89.86	90.43
S2	71.21	69.11	81.04
S3	90.13	89.21	90.68
S4	91.53	91.68	90.93
S5	79.44	81.91	80.91
S6	91.21	91.77	90.84
S7	85.71	88.16	83.62
S8	87.16	91.32	90.56
S9	94.27	93.82	94.88
S10	85.22	86.48	82.2
S11	76.32	72.59	78.16
S12	81.23	81.4	77.7
D1	21.66	58.64	46.26
D2	79.31	94.45	26.04
D3	56.49	54.45	56.1

Appendix D3: Mean fixation duration (MFD) (in milliseconds)

	TextA	*TextB*	*TextC*
P1	370	338	314
P2	296	283	273
P3	375	386	341
P4	204	207	231
P5	344	323	338
P6	239	219	219
P7	371	368	362
P8	445	389	363
P9	397	337	385
P10	250	255	242
P11	540	446	419
P12	568	519	416
S1	385	344	330
S2	218	219	240
S3	334	299	300
S4	422	484	371
S5	270	296	266
S6	270	302	290
S7	403	419	357
S8	308	356	325
S9	372	347	398
S10	221	235	215
S11	227	209	238
S12	270	241	254
D1	235	314	201
D2	280	364	186
D3	223	214	220

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