Simultaneous interpreting and working memory executive control

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Working memory is a complex cognitive component responsible for maintenance of information during processing. Interpreting research has so far focused on working memory capacity rather than on the central executive functions. In the study described here, 28 professional interpreters completed a battery of four central executive tasks and three simultaneous interpretations (from English into Czech or Dutch 'A'). The results show that: (a) certain measurable features of simultaneous interpreting are related to the central executive functions of working memory; (b) one working memory function (inhibition of distractors) seems to be related to interpreting experience, while the others (automatic response inhibition, updating, attention switching) do not; (c) the relationship between working memory and simultaneous interpreting is such that different working memory functions predict different sub-processes in simultaneous interpreting, in complex patterns. The conclusions of this study are data-driven, but in line with the current literature. More specifically, the findings support those accounts of simultaneous interpreting which emphasize attentional control as an important component of the simultaneous interpreting process.

Keywords: simultaneous interpreting, working memory, central executive, attentional control

Introduction

The concept of working memory is most influentially represented in a working memory model proposed by Baddeley (Baddeley 1996, 2000; Baddeley & Hitch 1974), which assumes several independent but interconnected components with specific functions. Chief among these are separate stores for verbal and visual

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information, and a supervisory mechanism known as the central executive. Most early research focused on testing the storage components of working memory, first through simple storage tasks and later through complex tasks. Simple storage tasks (e.g. digit span) focus exclusively on the storage capacity of working memory; complex tasks, such as the reading span task developed by Daneman and Carpenter (1980), combine storage and processing and are thought to better reflect the underlying construct of working memory. It was primarily through complex tasks that working memory was related to a host of higher cognitive processes, such as reading, problem-solving and intelligence (Feldman Barrett et al. 2004). Pure storage tasks typically show a weaker relationship with complex cognitive tasks (Jarrold & Towse 2006), and also with general fluid cognition (or general abstract intelligence) (Conway et al. 2002). On the other hand, it has been shown that individuals with large working memory capacity (high scorers on tasks such as the reading span task) do not perform significantly better than individuals with low working memory capacity in conditions where they are prevented from using the central executive functions (Engle 2002; Hester & Garavan 2005). This suggests that those with a large working memory span leverage the central executive to help them maintain information for later recall (Engle 2002).

The central executive remained a rather underexplored component of the working memory model for a long time. Baddeley (1996) made a call for more research into the central executive, and also outlined four main functions fulfilled by it: coordination of two tasks; switching of retrieval strategies; selective attention and stimulus inhibition; and holding and manipulation of information in long-term memory. Further research specified a number of others. For example, Oberauer, Süss, Wilhelm and Wittman (2003) proposed coordination and supervision as the main functions, with other subfunctions distinguishable within these broad categories. Friedman and Miyake (2004) placed particular emphasis on inhibition, whereby executive processes suppress interfering or distracting information. Two important points emerge from these developments in study of the central executive. First, it is not to be considered a unitary, single-function element; on the contrary, it can apparently be broken down into a number of other functions and/or components. Secondly, a typical central executive task, according to Baddeley (1996), is random number generation. In this task, participants are asked to generate a random sequence of numbers, naming them one by one. Importantly, the task does not include any explicit store-and-recall element. This indicates that central executive tasks can tap the *working* part of working memory, without necessarily tapping the memory part at all.

On the basis of these research findings, there seems to be a growing consensus that the crucial element of working memory tasks (complex span tasks) is controlled attention (also called executive attention and central executive) (Conway et al. 2005; Engle 2002; Engle & Kane 2004; Feldman Barrett et al. 2004). As Engle (2002) puts it, working memory capacity is not directly about memory — it is about using attention to maintain or suppress information. This new approach to the properties of working memory has led to two major changes of perspective. A first point is that, while maintenance of information in the face of other processing demands is still valid (e.g. Caplan & Waters 1999; Cowan 2000), the emphasis is now less on verbatim retention of information for subsequent recall than on broader concepts like maintenance of task goals (Engle 2002). Secondly, considering the crucial role played by the executive functions, high working memory capacity is now seen to imply not so much a large memory store as ability to keep information active and accessible (Engle 2002). This view means a very considerable shift away from the original focus on the *memory* component of working memory to its *working* part.

Working memory and language processing

Working memory has been shown to be related to many different areas of cognitive activity: reading comprehension; tasks involving fact retrieval and pronominal anaphoric reference (Daneman & Carpenter 1980; but see also Engle et al. 1999); lexical ambiguity resolution (Daneman & Carpenter 1983); paragraph comprehension (Waters & Caplan 2005); individual ability to make use of context to derive meaning of unknown words, both in comprehension and in production (Daneman & Green 1986); and interaction of syntactic and pragmatic information (Just & Carpenter 1992). These relationships hold when working memory is measured by complex span tasks, such as reading span, but not when it is measured by more traditional tasks such as digit or word span tasks (Daneman & Carpenter 1980). This raises the question as to which components of working memory are involved in language processing, and how.

Complex span tasks reflect both the passive stores and the central executive. Waters and Caplan (1996) found that, if the reading span task is scored both on recall (traditional method, developed by Daneman and Carpenter 1980) and on the processing component (which is normally disregarded), it is the latter which provides the better prediction of reading comprehension. This is suggestive of some executive component being involved, rather than just passive memory stores. Indeed, Gathercole and Baddeley (1993) concluded that most adult language processing does not require the phonological loop, which is part of the Baddeley & Hitch verbal storage component; instead, the authors claim, adult language processing depends more critically on the activities of the central executive. Similarly, Baddeley (2002) found that word recall is affected by disruption to the phonological loop, but sentence recall is disrupted by a concurrent central executive task.

The central executive itself is actually a collective name for a host of individual functions, and it is not obvious which one(s) should be responsible for language processing. Miyake, Just and Carpenter (1994) proposed that better performance in resolving lexical ambiguity is based on greater ability to keep information active. Gernsbacher and Foertsch (1999), on the other hand, argue that better working memory means more effective suppression of irrelevant information. Engle and Conway (1998) offer an explanation which accommodates both views, by underlining the importance of controlled attention — that is, the ability to keep relevant information active and to suppress irrelevant information. This explanation is neat and parsimonious, but goes back to the idea that the central executive is responsible without specifying in what way.

In any case, there seems to be an agreement that a substantial part of language processing is automatic (certainly in practiced users), and that working memory is employed only where the processing requires some effort. Engle and Conway (1998) concluded that comprehension can proceed, without employing working memory, whenever the content is produced in short, simple, affirmative sentences; when there are no intratextual references (such as pronominal anaphora); when words and phrases are completely unambiguous; when the content has a linear structure; and when there are no environmental distractions. Waters and Caplan (2005) found that working memory is not involved in syntactic parsing of a sentence, but does play a role in semantic integration of information in paragraphs. This suggests that skilled language use (as opposed to, for example, vocabulary learning) probably employs working memory for maintenance of intermediate products rather than raw language input (Cowan 1988; Logie 2006). For example, if a sentence contains an ambiguous word, it is important to keep all meanings of the word active until further context resolves which of the meanings is appropriate. Better performance on comprehension tasks is thus achieved by individuals with greater ability to keep more information active, and to select and/or suppress input according to its degree of relevance. It has been shown that, when syntax becomes ambiguous, individuals with lower working memory spans are less successful in the ambiguity resolution than those with high spans (Swets et al. 2007).

All in all, the role of working memory in language processing seems to be as a coordinator rather than a primary processor. As Was and Woltz (2007) point out, the amount of information needed for tasks as complex as language comprehension far exceeds the empirically verified capacity of working memory. This clearly indicates that much of what goes on during language processing must tap long-term memory. Was and Woltz refer to the available information as activated long-term memory. The same proposal was made by Ericsson and Delaney (1998), who claim that reading differences reflect differences in knowledge and acquired memory skills, and that reading span is a measure of long-term memory. Correspondingly, keeping items of information in working memory means not so much actually storing them as having them ready and in an active state (Engle & Conway 1998).

Simultaneous interpreting and working memory

Research into working memory and interpreting has so far focused on the use of traditional working memory tasks, measuring both simple and complex span (for detailed reviews, see Köpke & Signorelli 2012; Timarová 2008, 2012). The studies concerned have mainly examined one or the other of two basic questions. First, do intepreters have better working memory than non-interpreters? Second, is working memory related to interpreting? The first question has been addressed several times, but the evidence is ambiguous (Köpke & Signorelli 2012), perhaps slightly in favour of interpreters indeed performing better on working memory tests than non-interpreters. As for the second question, evidence for a relationship between higher working memory capacity and better overall interpreting performance (usually accuracy) has been found in interpreting students and untrained bilinguals (Christoffels 2004; Hodáková 2009; Tzou et al. 2012).

In terms of method used, most of the research on working memory in interpreting studies has been based on tasks which tap its storage components. When complex tasks were used, only the recall (i.e., the storage) part of the task was scored. Only one study used a specific central executive task. Köpke and Nespoulous (2006) addressed the question of working memory differences between professional intepreters, interpreting students and control subjects. One of the tasks they employed was the Stroop test (Stroop 1935), which is considered to measure inhibition of automatic responses (Miyake et al. 2000). Köpke and Nespoulous did not find any difference between the groups on this measure.

So far, interpreting research has not systematically addressed the involvement of the central executive component of working memory in interpreting. On a theoretical level, Moser-Mercer (2005) proposed that controlled attention may be an important component of interpreting, but this idea has not been tested empirically. Other theoretical work includes Mizuno's (2005) application to interpreting of Cowan's working memory model, in which controlled attention plays a central role. Gile's Effort Models (1995) also specify a coordination effort, which could reflect the executive control mechanisms of working memory.

Against this background, the study presented below explores the involvement of the central executive in simultaneous interpreting by professional interpreters. The specific questions addressed in the study are the following: 1. Is there a relationship between the working memory central executive functions and measurable features of simultaneous interpreting performed by professional interpreters? 2. Is the central executive involved in all aspects of simultaneous interpreting to the same extent, or do different functions of working memory support different processes in simultaneous interpreting? 3. Is the relationship between the central executive and simultaneous interpreting substantial? Do data support the notion that working memory is a crucial mechanism of simultaneous interpreting performance (Bajo et al. 2000; Darò 1989)?

Method

General methodological considerations

This was an exploratory study of individual differences in working memory and simultaneous interpreting, conducted with professional interpreters. Given the study's exploratory nature, priority was given to breadth rather than depth of investigation, and to description rather than explanation. To allow for statistical analysis, evaluation of interpreting was based only on quantifiable parameters: the absence of qualitative measures obviously means that a number of important aspects of the interpreting process could not be taken into consideration.

It should also be borne in mind that the limited size of the study sample (28 interpreters) inevitably affects statistical power and reliability. Calculation of the study's statistical power by G*Power 3 (Faul et al. 2007) indicates that, with a sample of 28 interpreters and a p-value of 5%, relationships with a Pearson correlation coefficient of $r = 0.5$ have an 80% probability of being found, while the probability of detecting relationships with a Pearson correlation coefficient of $r = 0.3$ is only 35%. There is, therefore, a very real possibility that some of the weaker relationships will not be detected.

It should also be noted that confidence intervals on the correlation coefficient are directly affected by sample size. For the above correlation of $r = 0.5$, found in a sample of 28 interpreters, the confidence interval is (0.16, 0.74). The true correlation could therefore be rather weaker or rather stronger than the one found in the sample. However, given the exploratory nature of the study, we were more concerned with forming an initial overall picture (and tentatively identifying any trends) than with finding the exact strength of the relationships.

Measuring the working memory central executive

Working memory is a complex construct and a range of tests exist. The selection of tasks for the present study was based on constructs and findings described in the literature. Four executive functions were thus selected for specific testing, to evaluate their potential relevance to interpreting. The functions concerned, which are briefly described below, were tested in isolation so as to facilitate interpretation of results.

Resistance to interference is required to keep focus on the task at hand and to avoid being distracted by irrelevant stimuli. These may include environmental factors, such as irrelevant sounds and noise, or task context factors unrelated to the goal of the task. In the context of simultaneous interpreting, the need to resist interference makes intuitive sense. Interpreters must disregard — or cope with — not only environmental factors but also distractions such as their own voice, which can compete with the source text for their attention.

Another inhibitory function is the *resistance to automatic (prepotent) responses*. Such responses may arise as a result of developed routines (automated behaviour), or of a triggering stimulus. Typical examples of this resistance in the interpreting context may be the avoidance of false cognates, or postponement of interpreting until sufficient information is available to allow for planning (e.g. not committing too early to a particular syntactic structure, so as to avoid problems later). The Stroop test, used by Köpke and Nespoulous (2006), taps this function.

The third function is *updating*. This function requires continuous evaluation of incoming information against information held in memory, followed by any necessary changes to memory content with a view to completing the task concerned. The resemblance to the demands of simultaneous interpreting can hardly be overstated: a continuous stream of incoming information needs to be retained briefly while it is being processed, and then 'flushed' to make room for new information.

The fourth executive function tested is *shifting* or task switching. Miyake et al. (2000) define this function as the ability to disengage from a current task and engage in a new one. This ability to switch between two tasks or two mental sets is again a requirement whose relevance to the interpreting context can be readily appreciated. Interpreters process an incoming stream of source language input and use it as the basis to produce their own output. There is evidence that interpreters monitor their own output (e.g. Petite 2003), and one possibility of managing the two streams is that interpreters switch between them.[1]

1. An alternative is that interpreters process both streams in parallel. This issue has not been studied in detail, and both possibilities remain theoretically possible. The switching hypothesis has a slight theoretical edge if interpreting is considered to be an attention-demanding process. Parallel processing would be plausible if interpreting is seen as routine and automated. This issue certainly merits more attention.

Measuring specific features of simultaneous interpreting

Simultaneous interpreting is a very complex skill and its measurement must necessarily be limited to just a few selected parameters. Three criteria were followed in the selection of variables: (1) theoretical interest for interpreting studies, and some degree of intuitive justification of why the measure should be related to working memory; (2) empirical feasibility, i.e., the possibility of measuring the variable objectively; (3) relevance of each variable to a different aspect of the interpreting process. The resulting variables were divided into two groups: local processes, measured at specific points (specific linguistic phenomena); and global processes, considered to span the whole task.

Local processing was measured with regard to lexical, syntactic and semantic phenomena. *Lexical processing* was operationalized as the interpretation of numbers or figures, traditionally considered difficult for the interpreter because devoid of semantic content: few other linguistic items are identified as so dependent on memory in the context of interpreting. *Semantic processing* was operationalized as the interpreter's handling of sentences containing double negations. Psycholinguistic research shows that a positive affirmative clause is neutral and unmarked; negative affirmative clauses, on the other hand, are marked, and therefore more difficult to understand (Clark 1969), requiring greater neural activation (Carpenter et al. 2000). In the context of interpreting, Bülow-Møller (1999) has shown that interpreters make more errors in marked sentences (negative, modal, etc.) than in unmarked sentences. Finally, *syntactic processing* was operationalized as interpretation of sentences with a complex syntactic structure. Specifically, Andrews, Birney and Halford (2006) have shown that greater working memory capacity is associated with more successful comprehension of sentences containing relative clauses, which require the integration of several nouns and verbs into the appropriate syntactic hierarchy. This is especially true of object-extracted relative clauses (King & Just 1991). Given the added difficulty of simultaneous interpreting, in comparison with self-paced monolingual reading, we opted for the simpler alternative of subject-extracted relative clauses.

Global processing measures included: active vocabulary, ear–voice span (EVS), and performance at different speeds of source text delivery. *Active vocabulary* is a measure of how varied and extensive the mental lexicon is. Higher working memory capacity has been associated with acquisition of new words (Baddeley et al. 1998), meaning inference and production (Daneman & Green 1986). In interpreting, Lamberger-Felber (2001) has shown there is great variability in the use of vocabulary by interpreters. In the present study, active vocabulary was operationalized into two measures: type/token ratio and unique vocabulary. The type/token ratio is a standard measure used in corpus linguistics. It compares the total number of words in the output (tokens) with the number of words used only once (types). On the other hand, unique vocabulary was measured as the number of words used only by a given interpreter. *EVS* is required in interpreting, where the interpreter must strike an appropriate balance between potentially conflicting priorities — the need to wait for a meaningful chunk of information, and at the same time to process the input fast enough so as not to overload memory. In an observational study of simultaneous interpreting from English to Korean, Lee (2002) proposed a "watershed" value of EVS, lag times greater than approximately four seconds being associated with increased error rates. However, EVS is highly variable in interpreters (Lamberger-Felber 2001). Finally, *speed of source text delivery* was manipulated in order to assess how interpreters cope with differing rates of input, and whether any differences in performance can be related to working memory. By this manipulation, interpreters are presented with different quantities of source language input in the same length of time. At higher speeds, interpreters have been shown not only to make more errors and omissions but also to increase their EVS (Gerver 1969/2002).

Study sample and specific methods

Participants

A total of 28 participants (18 females, 10 males) were recruited for the study. All participants were professional interpreters accredited to work for the institutions of the European Union. Each participant's mother tongue was either Czech (20 interpreters, of whom 15 were women) or Dutch (8 interpreters, of whom 3 were women), and their professional (accredited) language combination included English. Participants' mean age was 37.1 years (*SD* = 8.2 years), ranging from 25 to 55 years. All had a higher university degree (equivalent to at least four years' university education). Twenty-three participants were formally trained as interpreters, while the other five had no formal training.[2] All 28 participants were active interpreters at the time of testing, with interpreting as their main professional activity, either as staff interpreters at one of the EU institutions (European Commission, European Parliament) or as freelance interpreters for the same institutions (possibly complemented by activity on the private market). Professional interpreting experience ranged from one to 25 years, with a mean of 11.9 years (*SD* = 6.9 years).[3] Since professional activity in a year varies, participants were

2. Eligibility criteria to sit the EU inter-institutional interpreting test allow applications from individuals with formal training and/or proven professional experience.

3. Interpreters with no formal training in interpreting were among those with most years of professional experienc (mean = 19.0 years, *SD* = 4.2 years).

also asked to estimate the number of days they had worked for each year of their professional career, which were added up to give an estimated total number of days worked. The mean professional experience was 1457 days (*SD* = 1075 days, range 60–4500 days). Participants' mean subjective rating of English comprehension was 9.2 out of 10 (*SD* = 1.1). The mean age of English acquisition (i.e., when participants first started learning English, whether formally or informally) was 11 years (*SD* = 3 years). Twenty-five participants indicated that they interpret from English every time they work. The mean estimated proportion of working time dedicated to interpreting from English was 70% (*SD* = 18%). Twenty interpreters considered English their preferred relay language.[4] The mean number of working (non-native) languages was three (*SD* = 1.0). When working languages were ordered from strongest to weakest, the mean ranking of English among participants was 1.4 (*SD* = 0.6) — i.e., most participants rated English as their strongest working language.

Apparatus

All tasks (working memory and simultaneous interpreting) were presented on an HP Compaq nc8430 portable computer, with a 15.4-inch screen (maximum resolution 1680x1050) and Microsoft Windows XP Professional as the operating system. Working memory tasks were programmed and presented as computer-controlled experiments, using E-Prime 2.0 (Schneider et al. 2002). Responses to tasks were logged, using a standard keyboard, in E-Prime 2.0.

Simultaneous interpreting materials were recorded using a Sony HDV 1080i digital video camera. The recordings were then digitized, edited (picture and sound) on Microsoft Windows Movie Maker 5.1, and saved as *.avi* files (DVD quality video files). Participants' simultaneous interpretations were recorded with an external Philips SBC MD150 microphone, on a Roland Edirol R-09 24 wav/mp3 recorder. A Bandridge Soundstage 150 audio mixer was used to create a dual-track recording of the source text and interpretation.

Instruments

The paper-and pencil version of the Cattell Culture Fair Test Scale 3 (Cattell & Catell 1950), Part A, was used to establish participants' general cognitive abilities. The completion of the test was time-limited, with scoring based on the number of correctly solved problems.

4. The EU environment is highly multilingual: up to 22 different languages are spoken in meetings. Where an interpreter does not work from one of the languages spoken on the floor, e.g. Hungarian, s/he takes relay, i.e. interprets from a concurrent interpretation into a known language. The main relay languages at the EU are English, French and German.

Working memory tasks
Inhibition — resistance to interference: arrow flanker task. The design of the arrow flanker task was loosely based on Fan et al. (2002). In this task, the participants were asked to indicate the direction of a central arrow (left or right) presented between distractors. On each side of the target arrow, there were two dashes (neutral condition) or two arrows. The distracting arrows pointed in the same direction as the target arrow, or in the opposite direction (facilitating or interfering conditions respectively). To respond correctly, participants had to resist interference from the distracting arrows.

A black arrow appeared in the centre of a white screen, flanked by two arrows or dashes on either side. The five symbols together subdued a horizontal visual angle 3.8°; they appeared, for a total of 1500ms. The screen was then left blank for 500ms. Participants were asked to indicate the direction of the central arrow by using a left or right key. There were three flanker conditions: congruent (all five arrows pointing either left or right), incongruent (the central arrow pointing in the opposite direction to the four flanker arrows), and neutral (with the central arrow flanked by four dashes). The experiment consisted of 18 trials with feedback on accuracy and 102 experimental trials, with an overall duration of approximately 4'30". The dependent variable was the ratio of the mean response times in the incongruent condition and the neutral condition: the lower the score, the more limited the interference (and the more effective the inhibition of interference from irrelevant stimuli).

Inhibition — response inhibition: antisaccade task. The antisaccade task was modelled on Friedman & Miyake (2004). The goal was to indicate the direction of an arrow which appeared on the right or left side of the screen, preceded by a distractor appearing on the opposite side of the screen. To complete the task correctly, participants had to avoid visually following the distractor (and thus missing the arrow).

Participants were seated 45cm from the screen. A fixation point (a plus sign) was displayed in the centre of the screen for a variable length of time (between 1500ms and 3500ms), followed by a visual cue — a 0.3cm black rectangle, appearing 8.6cm to the left or right of centre (randomly), for 175ms. The target then appeared on the opposite side of the screen (again, 8.6cm to the left or right of centre): it consisted of a white block arrow, pointing upwards to the left or right and enclosed in a 1.5cm white square. After remaining on screen for 150ms, the target was masked by grey cross-hatching for a period of 1500ms. Participants then had to indicate the direction of the arrow. There were 22 practice trials, followed by 90 experimental trials. The dependent variable was the proportion of correct responses. This task lasted approximately 7'15".

Updating: 2-back task: The task was to indicate whether a letter currently presented on the screen was identical to a letter presented two steps back. A fixation point was displayed in the centre of the screen for 3000ms, followed by a letter for 500 ms, followed by another fixation point for 2500ms. Letters were presented in both upper and lower case to minimize visual memory. There was a practice list of sixteen items, and three experimental lists of 48 items each: two initial items, fifteen targets and 31 non-targets. These were divided into 25 neutral mismatches, and six interfering items: three were in the 1-back position, and three in the 3-back position. The dependent variable was the proportion of correctly identified letters. Approximately ten minutes were needed for this task.

Shifting: number-letter task. The task was modelled on two sources: Rogers & Monsell (1995) and Miyake et al. (2000). Participants were presented with a two-by-two grid, each cell being a 5cm x 5cm square. A number-letter pair (e.g. 7R) appeared in the centre of a cell. Participants performed one of two judgement tasks, depending on the location of the pair. For all pairs appearing in the top two quadrants, participants decided on the parity of the number (odd-even). For all pairs appearing in the bottom two quadrants, participants decided whether the letter was a vowel or a consonant. The task was presented in three blocks. In the first block, participants performed 32 number judgement trials (preceded by 10 practice trials). In the second, participants performed 32 letter judgement trials (with 10 practice trials beforehand). In the third block, the number-letter pair appeared in all four quadrants, starting from the top right quadrant and changing location clockwise: participants thus completed two number judgement trials, followed by two letter judgement trials. This led to a regular alternation of task-switching and non-switching trials, the total number of trials in this block being 128 (plus 12 practice trials). There was a total of eight digits (2–9), and eight capital letters — both consonants (G-K-M-R) and vowels (A-E-I-U). Each pair of one letter and one number, randomly generated from these lists, appeared on the screen until a response key was pressed; there was then a 150ms pause, followed by a new pair. The dependent variable was the switch cost, calculated as the difference between the median response times for the switch and non-switch trials in the third block. This task took approximately 5’30”.

Simultaneous interpreting measures

Text selection and manipulation

The three texts which were prepared and recorded for the simultaneous interpreting tasks were all based on contributions to a high-level “Business and Human Rights Seminar”, held in December 2005.[5] Text 1 was an edited version of a contribution by a representative of Amnesty International, slightly shortened for the

5. http://www.business-humanrights.org/

purposes of the study so as to last approximately 20 minutes when delivered at a moderate pace. A total of 30 sentences in the text were manipulated, to provide controlled material for the dependent variables. These sentences were of three types, each presenting one of the following difficulties: a) syntactically complex structure; b) semantic complexity; c) numbers (to test lexical processing). All thirty sentences were embedded into the text: each was kept separate from the others, so that no two manipulated sentences occurred in immediate succession.

Ten sentences featured a complex syntactical structure, consisting of *subject + subject extracted relative clause 1 + subject-extracted relative clause 2 + main verb + verb complements.* The sentences were first developed in English and then translated into the target languages (Czech and Dutch), to ensure that in both cases: a) the source text syntactic structure could be reproduced; b) interpreters would experience similar production demands (measured as the number of words separating the subject and main verb).

Another ten sentences were manipulated to contain semantic complexity, in the form of a double negation. Five sentences contained the structure *verb + free negative morpheme (not) + verb + free negative morpheme (not)*, as in *We did not decide not to go*; five sentences contained the structure *verb + free negative morpheme (not) + verb with incorporated negative morpheme*, as in *We did not disagree*. As in the case of syntactically complex sentences, the stimulus material was first produced in English, then translated into Czech and Dutch to verify the linguistic viability of the material and the approximate production demands, measured in the number of words required to express the same idea in the target language (for full details, see Timarová 2012).

Finally, ten sentences were manipulated to contain two or three numbers. In this case too, the sentences were first developed in English and then translated into Czech and Dutch: the target language versions were compared for overall sentence length (in words) and length of the embedded figures (in syllables).

Texts 2 and 3, both based on the original background material to the 2005 seminar, were designed to be approximately 5–6 minutes long when delivered at a moderate pace. The topics were human rights compliance by companies in Brazil (Text 2) and China (Text 3), with an identical introduction and conclusion in both cases. The main body of the text included: a) a list of the industrial sectors examined, and the number of companies analysed in each sector; b) a list of specific human rights, and the number of companies supporting each of these. Lists were either presented as such, or embedded in full sentences. Where the list was embedded, the context was identical in the two texts, so that the only difference between the two was in the lists. For each text, the length of lists (in words for semantic items, in syllables for figures) was matched in the original English and the target language translations (for full details, see Timarová 2012).

Video and audio recordings
All three texts were recorded by a native British English male speaker with a neutral accent. No attempts were made to oralize them, the intention being to make them challenging even for the most experienced interpreters, and to avoid any ceiling effect. The speed of delivery was 125 words per minute (wpm) for Text 1, while Texts 2 and 3 were read at different speeds (117 wpm and 138 wpm respectively) so as to test interpretation of embedded lists accordingly.

In all recordings, the speaker was seated against a white background at a table, with his head and torso in view. The recording allowed a good visual perception of the speaker's face and facial movements, including lip movements and hand gestures. While every effort was made to ensure maximum video and audio quality, the quality of sound was inferior to the standards interpreters are used to in their professional environment (although not to such an extent as to seriously hamper their performance). Prior to testing, a sample of the recording was tested and approved by three professional interpreters/researchers (none of whom participated in the study).

Performance measures
Syntactic processing: For the ten manipulated sentences with a complex syntactic structure, interpretation was assessed as either preserving or not preserving the subject-main verb agreement across the two intervening relative clauses. Accuracy and completeness of the rest of the sentence was not evaluated in any way. The maximum possible score was 10 (one point for each correct sentence).

Semantic processing: Disambiguation of the double negation was assessed as either correct or incorrect, irrespective of whether conveyed in the target language by an equivalent double negation or by an alternative means of expression (e.g., interpreting *Some companies do not respect the rule not to employ children* as *Some companies do not respect the ban on child labour*). Again, the maximum possible score was 10.

Lexical processing: The ten manipulated sentences contained a total of 24 numbers, each scored as completely correct (1 point) or incorrect (0 points). Approximation or rounding of figures was not accepted. The maximum possible score was 24.

Active vocabulary: This analysis involved comparison of the twenty Czech interpreters' type/token ratios. A segment of 374 words was selected from the middle of Text 1. Using the AntConc corpus management software (Anthony 2011), individual word lists were compiled from the transcribed interpretations. Each word list was exported to Microsoft Excel and 'cleaned': all numerals were deleted, as were morphological forms (declensions and conjugations) of the same word (e.g., *do — did — done*, negative forms of verbs, comparative and superlative forms of adjectives) other than personal pronouns, and all slips of the tongue and unfinished words. Mispronounced words were restored to their correct form. The resulting list contained all types (words with only one occurrence) used by each interpreter, making it possible to calculate the type/token ratio.

Unique vocabulary: A personal unique vocabulary score was also determined, this being the number of words used only by the interpreter concerned.

Ear–voice span (EVS): Lag time between source text and target text was measured at the beginning of the 30 manipulated sentences in Text 1, on the basis of semantic correspondence. This meant discounting any norm-induced initial fillers (used simply to mask any pauses in delivery, and not semantically related to the source text), such as *and as mentioned before*. Any sentences omitted in their entirety resulted in missing values. EVS was calculated as the distance between the two cue points (cue range length), using Adobe Audition (Adobe Systems Incorporated, 2003). This resulted in a maximum of 30 individual values for each participant. Because of wide variability in these values, median EVS was calculated for each interpreter.

Effect of source text speed: This measure used items listed in Texts 2 (delivered at 117 wpm) and 3 (138 wpm). Each text contained a total of 72 items (figures, industrial sectors, specific human rights).[6] All participants interpreted the faster text first. The total of correctly interpreted items in each text was counted, with a score of one point for every correct item, giving a maximum possible score of 72 for each text. As with the assessment of lexical processing in Text 1, approximations or partial interpretations (e.g. *food industry* instead of *food and beverage industry*; *45%, 45.4%* or *around 45%*, instead of *45.3%*) were judged incorrect. The effect of source text speed was measured as the difference in the number of correctly interpreted items. Additionally, the average of correctly interpreted items in the two texts was taken as a measure of accuracy in conditions of high speed of delivery.

Procedure

Interpreters were recruited by personal contact or email. Individual appointments were made for the tests; according to participants' availability, the testing took place either in their homes or in interpreting booths at their place of work. All participants completed the tests in the same order: arrow flanker task; number-letter task; antisaccade task; interpretation of Text 1; Cattell Culture Fair test; 2-back task; interpretation of Texts 3 and 2.[7] For the interpreting tasks, participants were

6. Some listed items were repeated in the text.

7. The test sequence described here refers only to tests included in the present report. The study was larger in scope and included other tests. See Timarová (2012) for further details of the complete study.

given basic background information (i.e., the seminar programme) beforehand, and shown a video recording of an introduction to the event (for full details, see Timarová 2012).

Results and discussion

Data were initially screened to identify outliers (±2.5*SD*) on the working memory tasks, making it possible either to delete them or to mitigate their influence through data transformation. Descriptive statistics for the working memory tests and interpreting measures are shown in Table 1. Reliability of all tests was generally good. For vocabulary measures, only data from the Czech interpreters were used, resulting in a smaller sample (20 interpreters) for the parameters concerned.

A series of two-way ANOVAs was conducted, to examine the relationship of sex and mother tongue to age and working experience (both in years and in days). All main effects of sex and mother tongue as well as all interactions were non-significant, indicating that there was no difference between men and women, or between Czech and Dutch speakers: sex and mother tongue will therefore not be considered as confounding variables in relation to participant characteristics. A series of independent samples *t*-tests was conducted, to examine differences between males and females on working memory tests and the test of general cognitive ability. Males performed significantly better than females on the antisaccade task (automatic response inhibition), with $M_{males}=.87$, $SD_{males}=.13$, $M_{females}=.73$, $SD_{females}=.12$, $t(25)=-2.80$, $p=.01$. On all other tests of working memory and the Cattell test, there were no differences between male and female interpreters. Another series of *t*-tests was performed to examine differences related to sex and mother tongue on the interpreting tasks: no differences were found between males and females on any of these measures, while the two language groups differed significantly on average accuracy in Texts 2 and 3 and, with marginal significance, on the difference in accuracy between these two texts. Specifically, Dutch interpreters achieved higher accuracy in the interpretation of Texts 2 and 3 ($M_{Czech}=49.47$, $SD_{Czech}=9.45$, $M_{Dutch}=57.93$, $SD_{Dutch}=8.04$, $t(24)=-2.10$, $p=.047$); and the effect of source text speed on their interpreting was smaller to a marginally significant degree than for Czech interpreters ($M_{Czech}=10.11$, $SD_{Czech}=6.39$, $M_{Dutch}=5.29$, $SD_{Dutch}=5.62$, $t(24)=1.76$, $p=.09$). There were no other differences associated with the interpreters' mother tongue.

Preliminary analysis showed that the data do not meet the assumptions of bivariate normality, and they were therefore analysed using non-parametric tests. Table 2 shows the correlation matrix (Spearman's rank correlation coefficient) of age, general cognitive ability and central executive tasks. The central executive

Table 1. Descriptive statistics for working memory tasks and interpreting measures

Measure	n[b]	*M*	*SD*	Range	Skewness	Kurtosis	Reliability[a]
Working memory central executive measures							
Updating: 2-back task (proportion correct)	27	89	.06	.72 to .97	−1.04	.98	.98
Resistance to automatic responses: antisaccade task (proportion correct)	28	.77	.14	.52 to 1.00	−.06	−.95	.93
Resistance to interference: arrow flanker task (interference effect)	27	1.07	.05	1.01 to 1.18	.64	−.60	.99
Shifting: number-letter task (switch cost, measured in ms)	27	516	254	107 to 1208	.73	1.05	.77
Simultaneous interpreting measures							
Lexical processing: numbers (number correct, max 24)	28	14.3	4.5	5 to 22	−.01	−.64	
Syntactic processing: syntax (number correct, max 10)	28	6.1	1.9	3 to 10	−.03	−.49	
Semantic processing: negatives (number correct, max 10)	28	7.3	2.1	3 to 10	−.41	−.97	
EVS: median ear–voice span (seconds)	28	3.2	.8	1.95 to 4.91	.49	−.24	
Active vocabulary (type/token ratio)	20	.55	.04	.46 to .60	−.66	−.08	
Unique vocabulary (number of words)	20	19.0	5.5	10 to 29	.38	−.77	
Speed effect: difference between Texts 2 and 3 (number of interpreted items)	26[c]	8.8	6.5	−3 to 22	.02	−.15	
Speed effect: average of Texts 2 and 3 (number of interpreted items, max 72)	26[c]	51.8	9.7	29 to 69.5	−.57	.06	
General cognitive measure							
Cattell Culture Fair Test (total correct)	28	28.3	4.46	17 to 36	−.46	.00	

[a] Reliability was calculated using the Spearman-Brown coefficient and split-half (odd-even) method.
[b] For working memory tasks, n lower than 28 reflects removal of outliers.
[c] Faulty recording resulted in loss of data for two participants.

tasks are not related to each other, with the exception of the 2-back task (updating) and the number-letter task (attention switching), which show a moderate correlation of −.37 ($p = 0.06$). Performance on all central executive tasks shows a general tendency to decline with age, with the exception of the arrow flanker task, although only the antisaccade task (inhibition of automatic response) correlates significantly with age. Once age is controlled for, the central executive tasks do not show a strong relationship with the Cattell Culture Fair Test of general cognitive ability.

The structure of the central executive tasks and their relationship to age are in line with our expectations. The general lack of relationships among these tasks supports the assumption that they are independent functions, and that it is sensible to test them separately. The weak negative correlations with age suggest a trend of cognitive decline, again in line with the general literature on human cognition. There is only one interesting relationship: the negative correlation of −.32 between age and the arrow flanker task (resistance to interference), indicating that this function tends to improve with age. This unexpected finding (the only one to emerge from the working memory tests) will require further examination.

Finally, the last two columns of Table 2 show the relationship between the central executive tasks and interpreting experience. Since interpreting experience is strongly related to age (more experienced interpreters are generally older than less experienced colleagues), the relationships shown are controlled for age.[8] Here, the pattern of results is very interesting, in that better performance on the arrow flanker task is related to both measures of experience. This is an exciting finding, because it indicates that interpreting experience may in fact be related to changes in the domain-general ability to focus attention and resist the influence of irrelevant distractors. This result may also explain the unexpected relationship between age and the arrow flanker task, as a hidden effect of experience. When age and the arrow flanker task are partially correlated, controlling for experience in years, the correlation is .19 (i.e. weak and positive), bringing this relationship back into line with the rest of the central executive structure. The relationship between the arrow flanker task and experience would receive further support if it were found to correlate with specific parameters of interpreting. The results of these and other analyses are shown in Table 3.

8. A more detailed analysis of the confounding effects of age can be found in Timarová (2012).

Table 2. Correlation matrix (Spearman) of age, general cognitive ability and central executive tasks

	Age	Cattell[b]	Anti-saccade	Arrow flanker	2-back	Experience[b]	
						Years	Days
Antisaccade	−.43*	.05				−.05	−.06
Arrow flanker[a]	−.32	−.29	.21			−.45*	−.55*
2-back	−.13	.31	.06	−.03		−.14	.05
Number-letter[a]	.29	.25	−.11	.06	−.37	−.19	−.32

$^*p < .05$
[a] lower value indicates better performance
[b] controlling for age (partial Pearson correlation on ranked data; Iman & Conover, 1979)

Table 3. Correlation matrix (Spearman) of simultaneous interpreting tasks, experience and working memory tasks

	Experience years[b]	Experience days[b]	Median EVS	Anti-sac-cade	Arrow flan-ker[a]	2-back	Number-letter[a]
Syntax	.21	.15	−.57*	−.17	−.30	−.04	−.12
Numbers	.39*	.29	−.50*	−.06	−.09	.52*	−.41*
Negatives	.51*	.53*	−.50*	.09	−.30	.09	−.02
Vocabulary: t/t ratio	.25	−.02	−.24	−.09	−.14	−.65*	.20
Vocabulary: unique	.30	−.02	−.01	−.17	.01	−.11	.12
Texts 2 and 3: difference	−.07	−.21	.15	.17	.14	−.13	.21
Texts 2 and 3: average	.42*	.39	−.57*	< .01	−.42*	.31	−.22
Median EVS	−.33	−.40*		.07	.09	−.27	.42*

$^*p < .05$
[a] lower value indicates better performance
[b] controlling for age (partial Pearson correlation on ranked data; Iman & Conover 1979)

The first two columns show the relationship between the various simultaneous interpreting tasks and the two measures of experience, controlling for age. Experience seems to be positively related to various measures of local processing (numbers, negatives and 'Texts 2 and 3: average'), but no relationship was found with measures of vocabulary or the effect of speed ('Texts 2 and 3: difference'). This indicates that more experienced interpreters tend to produce more accurate output, but there is little evidence of their producing more variable vocabulary. One interesting finding is the relationship between experience and EVS, which is shorter for more experienced interpreters. EVS is a measure of special interest, previously suggested as a possible indicator of underlying processing in interpreters

(Timarová et al. 2011). For this reason, the third column shows the relationship between EVS and other features of interpreting.

All three measures of local processing are negatively and significantly related to EVS. This means that those interpreters who kept shorter EVS were more successful in interpreting the measured items correctly. This is not a new finding. The literature on EVS discusses the question of striking the right balance between waiting in order to listen to more text and interpreting as soon as possible in order not to overload limited processing resources (de Groot 1997; Goldman-Eisler 1972; Setton 1999). Lee's (2002) empirical testing of the relationship between accuracy and EVS in simultaneous interpreting from English to Korean has already been commented on above (see 'Measuring specific features of simultaneous interpreting'). In the present study too, shorter EVS is seen to be associated with greater accuracy.

What is perhaps more interesting is the relationship between the 'Texts 2 and 3: average' parameter and median EVS: like the relationship with syntactic, semantic and lexical processing, this is again significant and negative. The difference here is that the EVS and 'Texts 2 and 3: average' measurements are independent, as they were each made on a different text, while the three measurements of local processing and EVS were made on the same material. The strong correlation between EVS and accuracy in another text suggests that EVS measures an underlying process which transcends the immediate context of a given interpreting task, and that it could potentially be a stable characteristic of interpreters' behaviour. A possible explanation in theoretical terms is offered by Moser-Mercer (1997), who hypothesizes that better knowledge organization in experienced interpreters results in faster access and retrieval. On an empirical level, de Groot (1997) analysed previous research on EVS, which yielded inconsistent results. Interpreters sometimes showed preference for a constant EVS over accuracy in adverse conditions, such as noise added to input (Gerver 1974, cited in de Groot 1997). When density and input rate were manipulated, however, EVS was longer. Our study employed materials free of noise (to the limit afforded by available technology), with very high information density and an input rate in the range of 120–130 wpm. It is nevertheless difficult to identify a single reason for the divergence between the present findings and those reported in the literature, as there are a number of important methodological differences: chief among these are the non-experimental inter-subject comparison made on a single text in the present study, and the experimental design comparing intra-subject performance in a number of conditions. Perhaps the best explanation is that the demands created by the input in the present study encouraged rapid processing in order to keep up with the speaker. In this sense, individual EVS may reflect the level of source text speed with which an interpreter can cope. By the same token, it is possible (even likely) that our participants' EVS would not necessarily have shown the same trend in response to different source text characteristics.

Let us now look at the relationship between simultaneous interpreting parameters and the central executive tasks. Of the four tested in this study, three show relationships with simultaneous interpreting, two of them on two measures each. First, interpretation of numbers is correlated with two measures of central executive functions: the 2-back task and the number-letter task. For both tasks, better performance is associated with a higher score on interpretation of numbers. In other words, interpreters who correctly interpreted more figures were also better able to update their memory and were faster at switching from one task to another. However, these two central executive tasks were the only ones which showed a potential relationship, i.e. a marginally significant moderate correlation (see Table 2). Further analysis of the relationship to numbers suggests that the correlation between the score for this parameter and the number-letter task is actually driven by the shared component of the 2-back task. Once the 2-back task is controlled for, there is no longer a relationship between figures and the number-letter task.

The 2-back task is also negatively related to type/token ratio, indicating that interpreters who updated their memory more efficiently tended to use less extensive vocabulary. This relationship is difficult to explain in conceptual terms. One possible explanation, based on knowledge of the mechanics of the 2-back task and interpreting, is that choice of vocabulary is subject to the processing speed associated with rapid updating of memory. Such an explanation is, however, difficult to demonstrate empirically: neither the 2-back task nor the type/token ratio are related to other variables, and there is therefore no converging evidence to support the explanation offered. This relationship is perhaps best left with a question mark for further research.

A relationship was also found between the arrow flanker task and the average number of correctly interpreted items in Texts 2 and 3. The arrow flanker task was correlated with interpreting experience, independently of age, and a correlation with an interpreting variable would further support this relationship. The correlation with 'Texts 2 and 3: average' shows that interpreters who were better able to block out distracting information were more accurate in their interpretation of isolated lexical items in these texts. It is rather disappointing that a similar relationship was not found between the arrow flanker and interpretation of numbers, which would have provided a basis for identification of a clear and consistent trend. Interestingly, the arrow flanker task also shows a (weaker) relationship with processing of both syntactic structures and negatives, again suggesting that better ability to resist distractors is related to greater accuracy on these two features of interpreting.

Finally, the relationship between the number-letter task and EVS indicates that interpreters who are better able to switch attention also keep shorter EVS. This is an potentially important finding. The relationship between EVS and efficiency in shifting from one task to another might provide a good basis for closer investigation of the underlying processes involved in simultaneous interpreting.

Conclusion

The basic research question we set out to explore is the relationship between the central executive component of working memory and simultaneous interpreting performed by professional interpreters. On the basis of our data, we constructed a network of relationships (Figure 1) and will use this "map" to draw tentative conclusions from our main findings. Before entering into detailed discussion, it should be clarified that the map is entirely data-driven; pending validation by means of an independent data set, it should therefore be considered only a provisional basis for study of the possible interaction between working memory and interpreting. Nevertheless, we believe it offers grounds for a number of general conclusions.

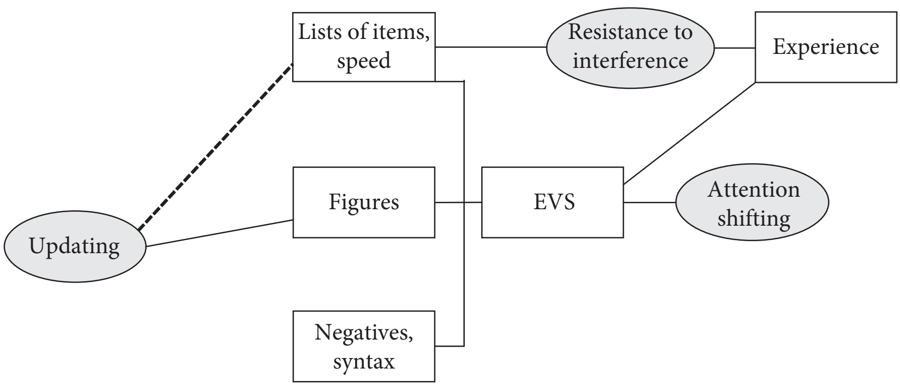

Figure 1. Relationships identified between working memory central executive functions and simultaneous interpreting: full lines represent significant relationships, the dotted line represents a trend.

The map shows five white rectangular boxes, representing the four features of simultaneous interpreting analysed above and the interpreters' length of experience; there are also three ovals, representing central executive functions of working memory. Several relationships can be identified between the ovals and squares: these links indicate that better performance on a given working memory function means better and/or faster performance on a selected interpreting parameter, thus lending empirical support to expectations based on the literature. In answer to our first research question, we therefore conclude that there is indeed some evidence of a relationship between the working memory central executive and simultaneous interpreting performed by professional interpreters.

The network of relationships is fairly complex, with some working memory functions related to more than one parameter of simultaneous interpreting. Interpreting of numbers is a case in point, and will be more successful if the interpreter: a) can quickly update information held in memory, in response to the demands of the task; b) keeps short EVS, which in turn requires c) the ability to efficiently switch attention between several tasks; and d) interpreting experience, which probably reflects a host of other skills and abilities. However, the overall pattern of relationships between individual working memory functions and specific features of the simultaneous interpreting process is complex: in some cases a given item is involved in more than one of these relationships, while other items show no such interdependence (and are thus not included in Figure 1). Therefore, in response to our second research question, we conclude that working memory is not involved in interpreting as one single entity: different working memory functions are related to different types of interpreting processes, in a complex network of interactions.

All four central executive functions depicted in Figure 1 are closely related to attention and coordination, and their involvement in interpreting on a general level makes intuitive sense. Simultaneous interpreters are constantly juggling with continuous source text input, which needs to be processed and reproduced in more or less real time. Control of attention, meaning ability to focus it where needed, has been proposed as a crucial component of interpreting (Cowan 2000; Moser-Mercer 2005). Liu et al. (2004) observed in an experimental study of simultaneous interpreting from English into Mandarin that more experienced interpreters were better at not missing critical segments, and tentatively suggested the ability to switch attention as an explanation. Their findings are broadly in line with those presented in this study. We would therefore like to propose that the present data add empirical support to suggestions about the role of attentional control (as a component of working memory) in interpreting. An additional question is whether this support extends to the idea of working memory playing a crucial role in interpreting, which was our third research question. The relationships with central executive functions found in our data, though all reasonably strong, are relatively few in number. One reason may be methodological: the features of interpreting selected for this study may not have been the best candidates to demonstrate the relevance of working memory, although the selection was made carefully on the basis of the available literature. Another possible explanation is that working memory is primarily involved in background processes which are difficult to measure in the product. This view would be supported by the predictive relationship between attention switching and EVS, which in turn is related to a whole range of phenomena in the final product. While both explanations are plausible, we conclude that the present data do not provide sufficient evidence to consider the working memory central executive as the most important underlying component of simultaneous interpreting.

Let us now consider more general implications of the present findings. Interestingly, and importantly, the data indicate that the relationship between simultaneous interpreting and working memory follows two distinct paths: one is related to experience of interpreting, while the other is not. Thus, Figure 1 shows that the ability to resist interfering distractors is related to experience and could develop in line with skill. The other two central executive functions (attention shifting and updating) do not show any association with interpreting experience, and we therefore conclude that they reflect cognitive abilities which are important for interpreting, but do not seem to develop with practice. However, if working memory does improve with experience, we would expect to see evidence of specific central executive functions playing a role in relation to interpreting performance. In the present data, the ability to resist interference was related to experience, but was found to correlate with only one feature of interpreting. More evidence is needed to show how working memory functions are related to interpreting, and how their development in relation to experience affects performance. One possibility is a suggestion by Cowan (2000) that the ability to ignore distractions is behind the findings in delayed auditory feedback studies, where interpreters were found to be less affected than students by listening to a delayed playback of their own voice (Fabbro & Darò 1995; Moser-Mercer et al. 2000). Ability to ignore distractors was found to be related to experience in the present study, and this empirical finding is in line with Cowan's suggestion. Having said that, the evidence presented here is of a correlational nature and does not allow for causal interpretation. One possibility is that only individuals with better ability to ignore distractions, for example, stay in the profession, while those who lack this ability change job. It is true that interpreting has a very high attrition rate, but we would argue that this peaks during and just after training. The interpreters in the present sample have all invested a great deal of time and resources in their training, employment and/or accreditation. While no data are available to us, we believe that by this stage in their careers interpreters are probably firm in their intention to pursue their chosen profession. Accordingly, even if we cannot state conclusively that practice leads to improvement in a given cognitive ability, it is a possibility which merits further study.

As for previous research on the central executive, only Köpke and Nespoulous (2006) tested a central executive function, using the Stroop test, a measure of ability to inhibit automatic responses. Testing of this ability was also included in the present battery of working memory tasks, since the antisaccade task assesses inhibition of automatic responses. Köpke and Nespoulous did not find any difference between interpreters and non-interpreters on this function; similarly, we found no evidence that it is related to interpreting.

Finally, let us briefly consider the present findings in the wider context of interpreting models. Mizuno (2005) put forward a proposal for using Cowan's model of working memory (Cowan 1999) as a basic conceptual framework for simultaneous interpreting. Cowan places emphasis on attentional control and activation of items in working memory, with both time and capacity limitations. In this perspective, successful interpretation implies rapid processing of items to avoid overload (Cowan 2000). The concept of attentional control, in the sense of active process management in order to avoid overload, is also central to Gile's (1995) Effort Models, as pointed out by Mizuno (2005). Both Cowan's and Gile's constructs thus provide a useful conceptual framework in which the present findings can be accommodated.

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