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An interpreter advantage in executive functions? A systematic review

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Abstract
The aim of this systematic literature review was to answer the question of which executive function is most affected by interpreter training and experience. We used the 'unity and diversity' framework of executive functions to distinguish between three executive components: *Response and Distractor Inhibition*, *Shifting*, and *Updating*. Among the seventeen studies included in the review, we only found evidence for an interpreter advantage on *Shifting* and *Updating*, but with a different pattern for each of these. With regard to *Updating*, groups of interpreters scored better than comparison groups, but general trend in longitudinal studies did not show an improvement for interpreter trainees. In contrast, for *Shifting*, scores improved as a result of interpreting training. Our systematic review stresses the importance of understanding the diversity of executive processes when investigating the relationship between interpreting and cognitive performance.

Keywords: cognitive control, executive functions, bilingual advantage, working memory

Introduction

Executive functions (or cognitive control) refer to a set of mental processes that regulate cognition, such as the ability to suppress task-irrelevant responses or to shift between mental sets (e.g. Diamond 2013; Miyake et al. 2000). Simultaneous interpreting has drawn the attention of scholars interested in executive functions because it is a complex activity that requires the simultaneous activation of two mental language sets in two different modalities (e.g. Injoque-Ricle et al. 2015; Yudes et al. 2011). As many studies on interpreting and executive functions show enhanced performance for groups of interpreters compared to comparison groups (e.g. Christoffels et al. 2006), an interpreter advantage hypothesis has been proposed which posits that active practice or training in the domain-specific skills engaged in interpreting transfers into a domain-general cognitive advantage (García 2014).

Given that executive functions refer to a multitude of processes, the question arises whether interpreting has a general effect on these processes or only influences specific subcomponents. This question can be answered through the various cognitive subdomains in which the interpreter advantage has been studied, one example being working memory capacity (e.g. Cai et al. 2015; Van Dijk et al. 2012; Wang 2016); others including task switching (or shifting) ability (e.g. Dong & Liu 2016; Dong & Xie 2014; Macnamara et al. 2011), mental (or cognitive) flexibility (e.g. Macnamara et al. 2011; Yudes et al. 2011), inhibition (e.g. Babcock & Vallesi 2015; Dong & Xie 2014), conflict resolution (e.g. Babcock & Vallesi 2017), selective attention (e.g. Morales et al. 2015; Woumans et al. 2015), updating (e.g. Dong & Liu 2016) and dual tasking (e.g. Strobach et al. 2015).

These studies have revealed mixed results regarding the question of which of these subdomains are selectively influenced by interpreting (compare, e.g., Timarová et al. 2014, who show a selective advantage on inhibition but not on flexibility, to Yudes et al. 2011, who show a selective advantage on cognitive flexibility but not on inhibition). We suggest that these conflicting results can be explained by understanding how the investigated cognitive subdomains relate to each other, as demonstrated by theoretical frameworks of working memory and executive functions, and by revealing how the interpreter advantage hypothesis

has been tested in a variety of research designs. Interestingly, two recent meta-analyses of studies on the relationship between interpreting and memory came to the conclusion that professional interpreters exhibit both greater working and short-term memory capacity (Wen & Dong 2019; Mellinger & Hanson 2019; for an excellent description of the advantages of using quantitative instead of qualitative review techniques, see Mellinger & Hanson 2020), but the authors of one of these meta-analyses at the same time expressed the need for reviewing other tasks of executive functioning to provide additional nuances on the exact relationship between interpreting and executive functioning in all of its variety (Mellinger & Hanson 2019).

Research on interpreting and cognition has seen a major shift from an initial interest in (working) memory (e.g. Christoffels et al. 2006) to a wider focus on executive functions (e.g. Timarová et al. 2014). The concept of working memory is related to that of executive functions, and some scholars have even conceptualised the latter as a subset of the mental processes involved in working memory (e.g. Baddeley 1992). According to one influential model (Hitch & Baddeley 1976), working memory can be subdivided into a central executive function responsible for the manipulation or processing of information, and two slave systems that store information: the phonological loop and the visuo-spatial sketch pad. An alternative view states that working memory only refers to the processing of information, and thus to the central executive, while the storage component is referred to as short-term memory (e.g. Colom et al. 2006; Unsworth & Engle 2006, 2007). Despite the obvious differences between these two viewpoints, they converge on the idea that the (central) executive functions are involved with the manipulation of information, and not with its storage. However, they reveal little about the variety of executive functions.

A coherent framework for how various cognitive control subdomains relate to each other is provided by the influential 'unity and diversity' model of executive functions (Miyake et al. 2000). This model has some clear advantages that may help us to specify in which subdomains interpreter advantages of executive functioning can be found. A first advantage is that this model has been empirically validated by latent variable analyses on scores from nine widely used tasks of executive functioning. These latent variables were labelled 'inhibition of prepotent responses' (or *Inhibition*), 'shifting between mental sets' (or *Shifting*), and 'updating of working memory representations' (or *Updating*), each of which could be related to scores on three of the nine examined tasks. A second advantage of the model is that structural equation modelling was used to determine how these three latent variables contribute to five additional complex tasks of executive functioning. For four of these tasks, a relationship could be established with one of the three latent variables (i.e. *Inhibition, Shifting* and *Updating*). In sum, the 'unity and diversity' model allows for a consistent classification of 13 of the most widely used tasks of executive functions into three subdomains and this classification can be used for a valid comparison of executive functioning across studies.

Not only do the executive processes being tested vary across studies, the literature also shows a wide range of research designs that have been used to test the interpreter advantage hypothesis. In its most straightforward form, the interpreter advantage refers to the finding of superior performance for groups of interpreters compared to comparison groups of matched non-interpreters (e.g. Christoffels et al. 2006; Morales et al. 2015; Yudes et al. 2011), interpreters with more years of training compared to interpreters at the initial stages of their training (Dong & Xie 2014; Tzou et al. 2012), and well-skilled interpreters compared to low-skilled interpreters (Macnamara et al. 2011), all using a cross-sectional design.

A major disadvantage of cross-sectional studies is that no causal relationships can be inferred from them. The finding of superior performance for interpreters over non-interpreters in a cross-sectional design can be explained from two opposing perspectives. One explanation is that the observed differences are related to pre-existing individual differences (see Hernandez et al. 2015) and that only individuals with high initial abilities are allowed (or

encouraged) to enter training programmes of interpreting or are able to proceed to the interpreting profession. An alternative explanation is that interpreter training or prolonged practice itself changes the strength and efficiency of executive functions, irrespective of initial cognitive ability. Longitudinal research designs with measurements before and after a specific intervention can disentangle both explanations and determine the directionality of the observed effects. The usage of this type of design has revealed significant progress on executive functions after having received training in interpreting (Macnamara & Conway 2014), or when interpreter trainees are compared to students of language and culture or of translation (Dong & Liu 2016).

Specifically, cross-sectional between-group (but not cross-sectional within-group or correlational) analyses are characterised by some drawbacks with regard to the interpretation of the reported results. One major disadvantage is that they neglect individual variability within an interpreter sample. It could be that these neglected individual differences related to specific aspects of the interpreting experience (e.g. the amount of professional experience, the amount of training, etc.) are directly connected to individual variation in executive functioning among participants. In line with this assumption, a few studies using a within-group (or correlational design) have revealed significant correlations between scores on executive functioning tasks and number of years of interpreting experience (Timarová et al. 2014), or measures of interpreting quality (Cai et al. 2015; Injoque-Ricle et al. 2015; Wang 2016).

The present study

Based on the 'unity and diversity' model of executive functions and reflecting the variety of interpreter advantages found in the literature on interpreting and executive processes, this systematic review intends to answer three research questions:

1) On which executive process (*Inhibition*, *Shifting* or *Updating*) do interpreters score better than a comparison group? This question can be answered by considering cross-sectional studies with between-group comparisons.
2) Which executive process is related to interpreting experience? This can be answered by an analysis of cross-sectional correlational or between-group studies.
3) Which executive process shows most progress during interpreter training? This can be answered mainly by looking at longitudinal studies.

In line with recent neuroimaging studies that have revealed a selective effect of interpreting experience and training on neural regions involved in executive functioning (Hervais-Adelman, Moser-Mercer & Golestani 2015; Hervais-Adelman, Moser-Mercer, Michel & Golestani 2015), we expect interpreting to have an effect on at least one of the three considered types of executive functions. Potential differences in response to research questions 1, 2, and 3 may reveal which executive processes are important in the selection of interpreter trainees, and which executive processes change as a result of interpreting experience and training. As such, this review could shed light on the malleability of each of the three considered executive processes as a function of intense language training in interpreting and interpreting experience.

Methods

Literature search and selection criteria

This systematic review followed the PRISMA guidelines and checklist to synthesise the existing literature (Liberati et al. 2009). Four databases (Google Scholar, ScienceDirect, Web of Science and Scopus) were searched with a cut-off date of 1 December 2016. All of the searches used variations of the following terms and key words: interpret(er)(ing), executive function(s)(ing) or process(es)(ing), cognitive control, shift(ing), update(e)(ing), inhibit(ion), and (working) memory. Tables of contents were inspected in peer-reviewed journals that focus on translation, interpreting and bilingualism-related topics. The electronic search, conducted by two authors independently, scanned each title and abstract, retrieving articles on the basis of their relevance to interpreting and cognitive control. Along with reviewing papers, some authors were also contacted through ResearchGate for additional information about their articles. Furthermore, the reference lists of publications located through these search methods were also inspected to identify studies cited therein. The inclusion criteria listed below were applied to the respective shortlists of papers:

1) The article was published in a peer-reviewed journal or a peer-reviewed book volume.
2) The participants included at least one sample of 'professional interpreters' or 'interpreter trainees'.
3) The tasks used in the study included at least one task of executive functioning. Task inclusion was based on the task characteristics rather than the label given by the authors.
4) The language of the article was English.
5) The study reported statistical analysis of the collected data.

Classification of articles

Classification according to task of executive functioning

The tasks from individual studies were classified into one of the three executive processes included in the 'unity and diversity' model (Miyake et al. 2000): *Inhibition*, *Shifting* and *Updating*.

First, *Inhibition* refers to one's ability to deliberately inhibit dominant, automatic or prepotent responses when necessary (Miyake et al. 2000). In the present study, a task was automatically classified into this component if it was one of the tasks mentioned in the 'unity and diversity' model (Miyake et al. 2000) as valid measures of *Inhibition*: the antisaccade task (Hallett 1978), the stop-signal task (Logan 1994), the Stroop task (Stroop 1935), or the Tower of Hanoi (Arnett et al. 1997); or if it was one of the tasks that taps into 'resistance to distractor interference', as measured, among others, by the flanker task or Simon task (Eriksen & Eriksen 1974; Simon & Rudell 1967). Using confirmatory factor analysis, Friedman and Miyake (2004) found that scores on tests of resistance to distractor interference and inhibition are closely related, and that these two constructs actually form one latent variable. For clarity's sake, we therefore chose to update the label '*Inhibition'* to '*Response-Distractor Inhibition'* (Friedman & Miyake 2004). Measures of '*Response-Distractor Inhibition'* can also be embedded within tests of attentional networks, such as the Attention Network Test (ANT) (Fan et al. 2002). The ANT is a combination of a flanker task and a cuing task (Posner 1980) and taps into the attentional networks of alerting, orienting, and executive functioning. Only the ANT measures of executive functioning, which are in essence flanker trials, were included in this review.

Second, *Shifting* is concerned with shifting back and forth between multiple tasks, operations or mental sets (Monsell 1996). In the present study, a task was automatically classified into this component if it was one of the tasks mentioned in the 'unity and diversity' model (Miyake et al. 2000) as valid measures of *Shifting*: any task-switching paradigm such as the plus-minus task (Jersild 1927), the number and letter task (Rogers & Monsell 1995), the local-global task (Navon 1977), or the Wisconsin Card Sorting Test (WCST) (Berg 1948). It

should be noted that task switching paradigms do not only tap into *Shifting* abilities, but may also elicit the recruitment of inhibitory processes (for a review, see Koch et al. 2010). This is especially so for the *n*-2 repetition cost (e.g. Scheil & Kleinsorge 2014), which refers to the additional time that is needed to access a task that was presented two trials before the current trial, but was inhibited on the previous trial. As most research seems to converge on the idea that this *n*-2 repetition cost in task-switching paradigms reflects the recruitment of inhibitory processes (e.g. Koch et al. 2004; Philipp et al. 2007; Philipp & Koch 2009), this *n*-2 repetition cost was included as a measure of '*Response-Distractor Inhibition'* instead of '*Shifting'*.

Third, *Updating* refers to the cognitive processes needed for monitoring and coding incoming information for its relevance to the task and appropriately revising and replacing old with new information in working memory (Morris & Jones 1990). In the present study, a task was automatically classified into this component if it was one of the tasks mentioned in the 'unity and diversity' model (Miyake et al. 2000) as valid measures of *Updating*: the keep track task (Yntema 1963), the letter memory task (Morris & Jones 1990), the *n*-back task (Jonides & Smith 1997), the tone monitoring task (Larson et al. 1988), and complex working memory span tasks (Bayliss et al. 2003). We chose not to include simple working memory span tasks because they are assumed to be related more to the storage capacity of short-term memory than to working memory updating abilities (Unsworth & Engle 2007).

Furthermore, we did not incorporate tasks that either are not related to any of the three executive functions as identified by the 'unity and diversity' model (Miyake et al. 2000), such as dual-tasking, or that are measures of *Resistance of Proactive Interference*, which is a construct unrelated to *Response-Distractor Inhibition* (Friedman & Miyake 2004), as well as the studies which did not answer any of three main research questions.

Selection based on statistical results

To answer the first and third research questions (and to some extent the second research question), either *F*- or *t*-values were extracted from cross-sectional studies with between-group comparisons or from longitudinal studies. To answer the second research question, in nearly all instances, *r*-values were extracted from cross-sectional studies with correlational analyses. In all cases, a *p*-value below .05 was chosen as the threshold for determining significance. If a study simultaneously included group comparisons among interpreters and non-interpreters and among interpreters with various degrees of experience or training, the values that came out of these group comparisons were attributed to the first, second, or third research questions depending on the comparison. For instance, a *t*-value that came out of a group comparison between interpreters and non-interpreters would be used to answer the first research question, and a *t*-value comparing interpreters with various degrees of experience would belong to the second research question, even though these values came from a single study. If different measures of one specific task were reported in a study, the results were considered as positive when at least one of the measures showed significant difference while the result was considered as negative when all of the measures in that task showed no significant differences.

Results

Selected articles

The electronic search resulted in a total of 1,798 articles. Many articles were included in more than one database; therefore, duplicate articles were removed first. Then, two researchers reviewed the titles, abstracts, and keywords of these articles for possible inclusion by applying the selection criteria stated above. When abstracts did not contain sufficient information to

determine inclusion or exclusion, the full text of the article was obtained and read. Articles that did not meet the selection criteria were excluded. In total, 17 articles met our strict inclusion criteria (see Figure 1).

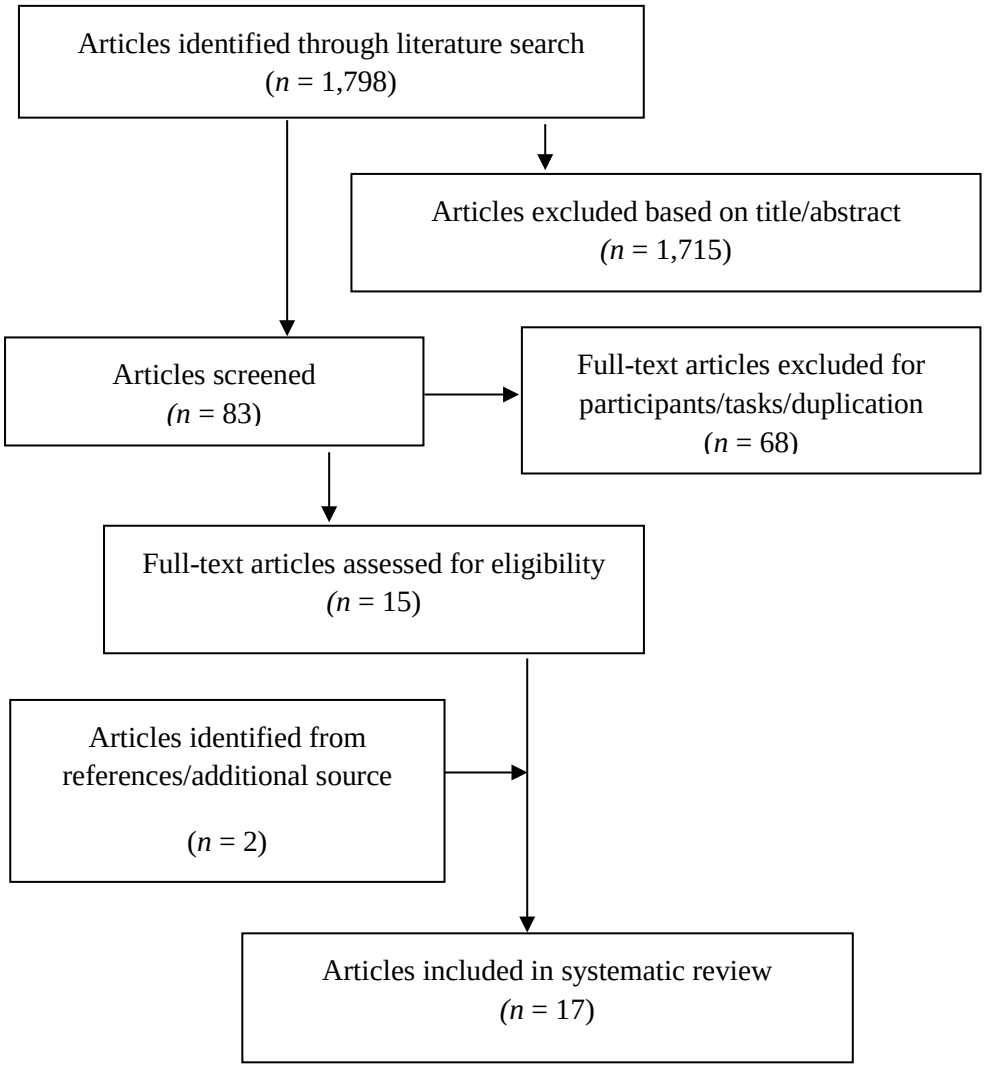

Figure 1. Flow diagram of articles selected for systematic review

Information on the research designs that were used in these 17 studies on the interpreter advantage in executive functions is given in Table 1.

Table 1. Research designs in studies on the interpreter advantage in executive functions

Design	Grouping characteristics	Number of studies
Cross-sectional	Between-group comparisons with one group of interpreters	7
	Between-group comparisons with more than one group of interpreters	6
	Within-group or correlational analyses	2
Longitudinal		3

Note. One study reports on experiments with cross-sectional and longitudinal designs, and is therefore counted twice in this overview.

These 17 articles report on a total of 94 tasks with 1,176 participants. From these 94 tasks, only 38 tasks were included in this review because they could be classified into one of the three executive functioning components revealed by the ‘unity and diversity’ model

(Friedman & Miyake 2004; Miyake et al. 2000): *Response-Distractor Inhibition*, *Shifting* and *Updating* as well as directly addressing at least one of their research questions of this review. An overview of the tasks included in this review, and the number of measures for each of the three executive functioning components can be found in Table 2.

Table 2. Tasks included and their number for each of the three executive functioning components

Executive functioning component	Tasks included	Number
Response-Distractor Inhibition	ANT (only executive functioning contrast), antisaccade, flanker, Simon, Stroop, task switching paradigm (only *n*-2 repetition cost)	11
Shifting	number-letter, task switching paradigm (only switch cost), WCST	7
Updating	complex span, *n*-back	19

Research question 1

Regarding the first research question (On which executive process do interpreters score better than a comparison group?), we determined that eight studies had tested the interpreter advantage in *Response-Distractor Inhibition* using 11 tasks in a cross-sectional design with between-group comparison including at least one group of interpreters and at least one group of non-interpreters. From these, two tasks show better performance for groups of interpreters and eight tasks show no effect of interpreting groups (either professionals, novices or students) (see Table 3). In Köpke and Nespoulous (2006), the Stroop task (two monolingual and two bilingual versions) was used to compare professional interpreters (experts), second-year interpreting students (novices), and two comparison groups (multilinguals and students). No between-group differences were found in the Stroop tests. The only group difference was obtained in the French bilingual Stroop (L1) where the novice interpreters performed significantly better than both the expert interpreters and a comparison group of bilinguals. This result, however, as explained by Köpke and Nespoulous (2006), does not necessarily mean more highly-developed selective attention skills in novice interpreters but is more likely due to a lack of balance between the languages in the novice interpreters. Four groups of monolinguals, unbalanced bilinguals, balanced bilinguals and student interpreters were tested on the Simon task and the ANT in Woumans et al. (2015). The results showed a larger Simon effect and higher overall RTs in the ANT for monolinguals compared with all bilingual groups. The three bilingual groups did not differ on overall RTs or the congruency effect, but interpreters and balanced bilinguals showed better orienting skills than unbalanced bilinguals and fewer errors only in interpreter students compare to unbalanced bilinguals. According to these results, interpreters showed cognitive control advantages on overall accuracy scores in both tasks, but only relative to unbalanced and not to balanced bilinguals.

We discerned four studies that tested the interpreter advantage in *Shifting* using a cross-sectional design with between-group comparisons including at least one group of interpreters. All these studies found a positive effect of interpreting groups (either professionals, novice, and students) compared to non-interpreting group (either bilinguals, multilinguals, monolinguals, or language teachers) (see Table 3). Babcock and Vallesi (2015) reported that the interpreter group showed greater sustained control on the task-switching paradigm (i.e. smaller mixing cost) than the multilingual group, though no difference was seen in transient control (i.e. switching cost). Dong and Xie (2014) found that two groups of beginner/advanced interpreting students perform better than two comparison groups of English students on the following measures of WCST: number of completed categories, overall errors, perseverative errors, and previous-category errors. However, no group

differences were found on global reaction times. The same results were reported by Yudes et al. (2011) for monolinguals, unbalanced bilinguals and professional interpreters showing that interpreting enhances cognitive flexibility using the same task. However in contrast to Dong and Xie (2014), interpreters did not differ from monolinguals or bilinguals in the global number of completed categories, but they were able to complete the task in a more efficient way. This efficiency was observed in the reduced number of attempts to infer the sequence of rules and in the smaller number of errors and fewer previous-category perseverations, which means that after a dimensional shift (e.g. from colour to shape), interpreters to a lesser extent continued classifying stimuli according to the previously relevant dimension (e.g. colour) instead of the newly relevant one (e.g. shape).

Table 3. Results of tasks answering Research question 1

Article	EF comp.	Research design	Task(s)	Results
Babcock & Vallesi (2015)	R-D I.	cross-sect., 1 group I	Task-switching	NS
Babcock & Vallesi (2017)	R-D I.	cross-sect., 1 group I	Stroop	NS
		cross-sect., 1 group I	ANT	NS
	Shift.	cross-sect., 1 group I	Task-switching	I+
	Upd.	cross-sect., 1 group I	Complex span	I+
Christoffels et al. (2006)	Upd.	cross-sect., 1 group I	Complex span	I+
Dong & Xie (2014)	R-D I.	cross-sect., 1 group I	Flanker	NS
	Shift.	cross-sect., >1 group I	WCST	I+
Dong & Liu (2016)	R-D I.	cross-sect., 1 group I	Stroop	NS
	Shift.	cross-sect., 1 group I	Task-switching	I+
	Upd.	cross-sect., 1 group I	*N*-back task	I+
Köpke & Nespoulous (2006)	R-D I.	cross-sect., >1 group I	Stroop	NS
	Upd.	cross-sect., >1 group I	Complex span	I+
Morales et al. (2015)	R-D I.	cross-sect., 1 group I	ANT	NS
	Upd.	cross-sect., 1 group I	*N*-back task	I+
Signorelli et al. (2011)	Upd.	cross-sect., 1 group I	Complex span	I+
Stavrakaki et al. (2012)	Upd.	cross-sect., 1 group I	Complex span	NS
Tzou et al. (2011)	Upd.	cross-sect., 1 group I	Complex span	I+
Woumans et al. (2015)	R-D I.	cross-sect., 1 group I	Simon	I+
		cross-sect., 1 group I	ANT	I+
Yudes et al. (2011)	R-D I.	cross-sect., 1 group I	Simon	NS
	Shift.	cross-sect., 1 group I	WCST	I+
	Upd.	cross-sect., 1 group I	Complex span	I+

Note. EF comp. = executive functioning component. R-D I. = Response-Distractor Inhibition. Shift. = Shifting. Upd. = Updating. cross-sect. = cross-sectional design. 1 group I = only one group of interpreters was included. >1 group I = more than one group of interpreters was included. I+ = interpreter advantage. NS = no significant difference.

We determined nine tasks that had tested the interpreter advantage in *Updating* using a cross-sectional design with between-group comparisons. From these nine tasks, eight *Updating* tasks found a positive effect for one group of interpreters (either professionals or trainees) as compared to a non-interpreting comparison group (either bilinguals, multilinguals, monolinguals, or language teachers) and one task found no effect (see Table 3). Stavrakaki et al. (2012) showed no main effect of group in listening recall span for the largest span achieved between professional simultaneous interpreters, foreign-language teachers and monolingual comparison group.

Research question 2

Regarding the second research question (Which executive process is related to interpreting experience?), we found that two studies had tested this in *Response-Distractor Inhibition* using three tasks (see Table 4). Köpke and Nespoulous (2006) used a cross-sectional design

with between-group comparisons and reported no between-group differences in the Stroop task when professional interpreters (experts) were compared to second-year interpreting students (novices). Timarová et al. (2014), who used a cross-sectional design with a correlational analysis, did not find any correlation between interpreting performance and the antisaccade task but found a negative correlation (r = -.55) between the number of days of interpreting and response time on the flanker arrows task, suggesting that interpreters' ability in that task improves with more interpreting experience.

Table 4. Results of tasks answering research question 2

Article	EF comp.	Research design	Task(s)	Results
Injoque-Ricle et al. (2015)	Upd.	cross-sect., corr. IE	Complex span	NS
Köpke & Nespoulous (2006)	R-D I.	cross-sect., > group IE	Stroop	NS
	Upd.	cross-sect., >1 group IE	Complex span	NS
Liu et al. (2004)	Upd.	cross-sect., >1 group IE	Complex span	NS
Signorelli et al. (2011)	Upd.	cross-sect., >1 group IE	Complex span	NS
Timarová et al. (2014)	R-D I.	cross-sect., corr. IE	Antisaccade	NS
		cross-sect., corr. IE	Flanker	IE+
	Shift.	cross-sect., corr. IE	Number-letter	NS
	Upd.	cross-sect., corr. IE	*N*-back task	NS

Note. EF comp. = executive functioning component. R-D I. = Response-Distractor Inhibition. Shift. = Shifting. Upd. = Updating. cross-sect. = cross-sectional design. >1 group IE = more than one group of interpreters was included. corr. = correlational. IE+ = advantage for interpreters with more experience. IE- = advantage for interpreters with less experience. NS = no significant difference.

We established that one study tested the effect of interpreting experience on *Shifting* using a cross-sectional design with correlational analyses and reports no correlation between interpreting expertise and shifting ability (Timarová et al. 2014). We found five studies testing the relationship between interpreting experience and *Updating* using a cross-sectional design with correlational analyses or a between-group comparisons that involve more than one group of interpreters. None show any correlation between interpreting experience and the *Updating* skill.

Research question 3

Regarding the third research question (Which executive process shows most progress during interpreter training?), we determined that only one study on *Response-Distractor Inhibition* had used a longitudinal design. This study does not show a relationship between interpreter training and *Response-Distractor Inhibition* (see Table 5).

We found three studies on *Shifting* employing a longitudinal design. These studies all show better performance for students with longer interpreting training (see Table 5). The longitudinal study by Dong and Liu (2016) showed that interpreting training produced a significant improvement in switching using the colour-shape task for interpreting students. Following the same trend, two longitudinal studies explained the role of interpreting training on *Shifting*. Macnamara et al. (2014) tested interpreting students at the beginning and the end of their training. The advanced interpreter students outperformed themselves as beginning interpreter students in the mean score on *Shifting* using WCST. In another longitudinal study by Macnamara and Conway (2016), the results again show that *Shifting* significantly improved after two years of interpreting training.

Table 5. Results of tasks answering research question 3

Article	EF comp.	Research design	Task(s)	Results
Dong & Liu (2016)	R-D I.	longitudinal, IT	Stroop	NS
	Shift.	longitudinal, IT	Task-switching	IT+
	Upd.	longitudinal, IT	*N*-back task	IT+

Macnamara & Conway (2014)	Shift.	longitudinal, IT	WCST	IT+
	Upd.	longitudinal, IT	Complex span (2)*	NS
Macnamara & Conway (2016)	Shift.	longitudinal, IT	WCST	IT+
	Upd.	longitudinal, IT	Complex span	NS

Note. EF comp. = executive functioning component. R-D I. = Response-Distractor Inhibition. Shift. = Shifting. Upd. = Updating. IT+ = advantage for interpreters with more training. *(2) = two different complex spans. NS = no significant difference.

We discerned three studies on *Updating* which used a longitudinal design. Two studies show no relation between interpreting training and *Updating* skill (see Table 5). Only one study shows a positive effect of interpreting training on *Updating*. Dong and Liu (2016) tested three groups of interpreting student, translation students and general L2 students in the beginning and at the end of one academic semester using the *N*-back task. The results show that both groups of interpreting students and translation students improve in their *Updating* ability (global RTs) but not the students who took a general English course.

Discussion

The goal of this systematic review was to clarify and classify the relation between various executive functions and interpreting experience and training to see where we can find any advantage for interpreters in these functions. A total of 17 articles were found and the tasks included in these articles were classified according to the empirically validated 'unity and diversity model' (Friedman & Miyake 2004; Miyake et al. 2000) into three components: *Response-Distractor Inhibition*, *Shifting* and *Updating*. The results revealed that interpreting experience or training differentially affect each of these three components. The following section is structured according to the three research questions asked in this study.

On which executive process do interpreters score better than a comparison group?

Our analysis on between-group comparisons with at least one group of interpreters and at least one comparison group has revealed interpreter advantages in all incorporated studies on *Shifting* (see Table 3) and in all but one study on *Updating* (see Stavrakaki et al. 2012 for the only exception), but in only two out of eight studies on *Response-Distractor Inhibition* (Köpke & Nespoulous 2006; Woumans et al. 2015). In both occasions, the contradictory finding of an inhibitory advantage for interpreters can be related to the selection of the comparison groups. Woumans et al. (2015) only found an advantage for interpreters when their performance was contrasted to comparison groups of monolinguals and unbalanced bilinguals but not to a comparison group of balanced bilinguals. In the study by Köpke and Nespoulos (2006), an interpreter advantage on *Response-Distractor Inhibition* was selectively found for novice interpreters but not for expert interpreters when their performance was compared to a bilingual comparison group. Moreover, the novice interpreters outperformed the two other groups only on the L1 but not on the L2 condition of a bilingual Stroop task (Stroop 1935). This finding was assumed to result from a lack of balance between the languages in the novice interpreters, the dominant language being less affected by interference from the non-dominant language than vice versa (Köpke & Nespoulous 2006).

Interestingly, interpreter advantages on *Shifting* and *Updating* have been observed over comparison groups of bilinguals and monolinguals alike. This is remarkable because previous studies have suggested the existence of bilingual advantages on these two components of executive functioning (e.g. Bialystok 2010; Prior & MacWhinney 2010; but see also Rosselli et al. 2016). The interpreters' better performance over non-interpreter bilinguals may be explained by the fact that interpreting involves extreme language control

(Hervais-Adelman, Moser-Mercer, Michel & Golestani 2015), for which executive functions such as *Shifting* and *Updating* may need to be tapped into more. Even though bilingual advantages have also been reported on *Response-Distractor Inhibition* (e.g. Blumenfeld & Marian 2014; Kazemeini & Fadardi 2016; but see also Morton & Harper 2007), our review suggests that interpreting does not seem to entail additional requirements related to this skill.

Which executive process is related to interpreting experience?

Our analysis of between-group comparisons with more than one group of interpreters based on their years of experience and of correlational studies has revealed no relationship between interpreter experience and *Updating* (see Table 4) or *Shifting* (Timarová et al. 2014), but mixed results regarding this relationship on *Response-Distractor Inhibition* (Köpke & Nespoulous 2006; Timarová et al. 2014). Interestingly, the tasks used to measure *Response-Distractor Inhibition* show different sensitivity: Köpke and Nespoulos (2006) found no difference between professional interpreters and interpreter students on a Stroop task. Timarová et al. (2014) used two different inhibition tasks with mixed results: a significant correlation between *Response-Distractor Inhibition* and interpreter experience was only found on the flanker task, but not on the antisaccade task. It should be noted that only the antisaccade task was included in the initial version of the 'unity and diversity' model as a valid measure of the latent variable '*Inhibition*' (Miyake et al. 2000). In this systematic review, we chose to include measures of *Resistance to Distractor Interference*, such as the flanker, as examples of an overarching *Response-Distractor Inhibition* component, because previous research has shown that these measures are closely related to tasks of *Response Inhibition*, such as the antisaccade and the Stroop task (Friedman & Miyake 2004). The outcome of our review suggests that both inhibitory subcomponents may be differently sensitive to the effects of interpreter experience with a selective effect only on *Resistance to Distractor Interference* but not on *Response Inhibition* (Timarová et al. 2014).

The absence of a relationship between the executive functions and interpreter experience seems to contradict what we observe in the analysis for Research Question 1, where interpreters show an advantage in *Shifting* and *Updating*. One possible explanation for this surprising finding may be that professional interpreters have reached a high level of expertise such that the processes involved in interpreting have become automatised and no longer require the recruitment of domain-general cognitive control in their professional practice (Hervais-Adelman, Moser-Mercer & Golestani 2015). However, as revealed by the outcomes of Research Question 1, they still may outperform non-interpreters because they may already have had better executive functioning capacities before entering the profession, for instance as a result of interpreter training (see below).

Which executive process shows most progress during interpreter training?

In contrast to the previous questions, our analysis of longitudinal studies has revealed a consistent pattern of results. While all reviewed studies show a training effect on *Shifting* (Dong & Liu 2016; Macnamara & Conway 2014; Macnamara & Conway 2016), only one of the reviewed studies shows a positive effect of interpreting training on *Updating* (Dong & Liu 2016) and not a single study reports any relationship between interpreting training and *Response-Distractor Inhibition.*

In fact, *Shifting* seemed to be the only cognitive control component that showed improvement from interpreting training as compared to other types of training such as second language acquisition and translation (Dong & Xie 2014). As mentioned in our discussion of Research Question 2, no correlation was found between *Shifting* and interpreting experience, the effect of training shown in this part of the analysis may be explained by a higher reliance

on shifting abilities while the interpreting skills are still being acquired. One longitudinal study shows a significant effect of interpreting training on *Updating* skills (Dong & Liu 2016), but this improvement is not specific to student interpreters since a comparison group of student translators also displayed similar progress. It will be interesting to see from future research to what extent any observed interpreter advantages reflect pre-existing individual differences or result from interpreting training.

Integration into theory of executive functions

While answering the three research questions above, it became clear that some executive functions, such as *Shifting*, are more sensitive to interpreting training, and others, such as *Updating*, are not. In contrast, the *Response-Distractor Inhibition* factor is neither sensitive to interpreting training nor experience. This pattern of selective trainability of executive functions may be integrated into the ACE (A: additive genetic, C: common environmental, E: non-shared environmental) genetic model of Friedman et al. (2016), who have examined genetic and environmental stability and change in three executive processes, measured with latent variables, from late adolescence to early adulthood in twins. The study reports that individual differences in executive functions are relatively heritable and stable by late adolescence but are still sensitive to environmental influences with different degrees of sensitivity for each of its components.

The ACE genetic model has revealed that this sensitivity is lowest for the *Updating*-specific component, with little or no room for changes in function of environmental influences (Friedman et al. 2016). In line with this, our systematic review reports that the *Updating* skill is not sensitive to interpreting training and interpreting experience. As for *Response-Distractor Inhibition*, the ACE model shows that nearly 20% of its variability is sensitive to environmental factors (Friedman et al. 2016). Highest sensitivity to environmental factors is found for *Shifting*, with over 20% of its variability attributable to non-genetic factors (Friedman et al. 2016). In our review, *Shifting* likewise turns out to be the executive process that is most sensitive to interpreter training.

To conclude, our systematic review shows that interpreting groups score better on *Updating* and *Shifting* compared to non-interpreters but not on *Response-Distractor Inhibition*. However, different components show different sensitivity to environmental influences such as training or professional experience, with a clear and selective effect of interpreter training on the *Shifting* component.

While interpreting the results of this systematic review, we must take into account a number of limitations we had to face in the process of this study. A first limitation of the current study is that we have used a model from cognitive psychology (Miyake et al. 2000) as a theoretical framework for answering research questions in another discipline, i.e. interpreting studies, with its own tradition, terminology, and publication outlets.[1] Doing so, we have classified some of the tasks used in particular studies into another construct than initially intended by the researchers themselves. For the purposes of this review, for instance, we considered complex span tasks as measures for *Updating* in line with the 'unity and diversity' framework, while they were operationalised as measures for working memory capacity in most of the original studies (e.g. Macnamara & Conway 2016). We admit the limitation of this methodological choice but at the same time believe that the application of a model from another discipline enhances the originality of the current study. The observation that scores of interpreters on tasks of executive functions to some extent depend on the distinction proposed by Miyake et al. (2000) between *Response-Distractor Inhibition, Shifting*

[1] We would like to thank one of the anonymous reviewers for drawing our attention to this limitation of our study.

and *Updating* suggests the value of reviewing the cognitive literature on interpreting from a 'unity and diversity' framework. A second limitation of our review is that our answers to the second research question (interpreting experience effect) were only based on two studies for *Response-Distractor Inhibition* and one study for *Shifting*, and should therefore be interpreted with caution. A third limitation of this review is the small variability in research designs that have been used to test the interpreter advantage. While over 13 studies have chosen a cross-sectional design with between-group comparisons, only three studies have used a longitudinal design, and only two studies have conducted correlational analyses. On *Response-Distractor Inhibition*, we could not find a single longitudinal study to test the trainability of this skill in interpreters. Therefore, we strongly recommend further investigation into the effect of interpreter training using a pre- and post-test design, as this has the greatest potential to single out effects that are specifically related to interpreting experience and training from effects related to genetic or other non-environmental factors.

Conclusion

This systematic review has used the 'unity and diversity' model of executive functions to answer research questions on the locus of the interpreter advantage. First, our review of cross-sectional research with between-group comparisons has clearly revealed that interpreter advantages in executive functioning are only found on *Shifting* and *Updating*, but not on *Response-Distractor Inhibition*. Second, our review of longitudinal designs has further restricted the effects of interpreter training to *Shifting*. We conclude that domain-general control requirements related to *Shifting* and *Updating* abilities may be critically involved in interpreting, but more research is needed to reliably establish whether between-group differences reflect initial (pre-training) differences or are a result of training and professional experience.

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