Articulatory suppression in language interpretation: Working memory capacity, dual tasking and word knowledge*

How do interpreters manage to cope with the adverse effects of concurrent articulation while trying to comprehend the message in the source language? In Experiments 1–3, we explored three possible working memory (WM) functions that may underlie the ability to simultaneously comprehend and produce in the interpreters: WM storage capacity, coordination and word knowledge. In Experiments 1 and 2, interpreters, high span individuals and control participants performed free recall tasks under normal, articulatory suppression conditions (Experiment 1) or while performing a secondary task (Experiment 2). In Experiment 3, professional interpreters free recalled nonwords or words in their first (L1) and second language (L2). The results indicated that the ability of the interpreters to simultaneously comprehend and produce is related to word knowledge rather than to an increased WM storage capacity or to an enhanced ability to coordinate processes and tasks.

Introduction

Translation and language interpretation are complex tasks that impose large demands on an individual’s cognitive resources. For example, in simultaneous interpreting, many processes are performed concurrently, in different linguistic codes and under strong temporal pressure. The interpreter must attend to and comprehend the discourse in a source language (SL) while mentally translating and overtly producing a translation in the target language (TL) (Gerver, 1974).

The theories proposed in the field of interpreting (Gile, 1997) emphasize the role of working memory (WM) in producing quality interpretations. Although there is not a general agreement about what WM is (see Miyake and Shah, 1999), one of the most influential theories (Baddeley, 1986, 1996, 2000) proposes that it is composed of a central executive and phonological and visual subsystems. The function of the two storage subsystems is to maintain phonological or visual/spatial information while the central executive is engaged in control processes. Finally, an episodic buffer keeps active the long-term knowledge structures needed to perform a given task (Baddeley, 2000).

Gile (1997) proposed that, in interpreting, five major processes require WM resources: (a) Analysis and understanding of the discourse in L1. Thus, like normal listeners, the interpreter has to access the lexical forms and the meaning of the words involved, assign syntactic roles, connect new information with information already in memory, etc. (b) Reformulation from L1 to L2. The translator should switch from L1 to L2 codes to access the lexical forms in L2 and assign new syntactic roles. (c) Storage of information in WM. Input sentences in L1 have to be maintained until reformulation takes place. In addition, the partial results of the reformulation process should be held in memory until correct translations are produced. (d) Production. Once reformulation has taken place, planning and performing speech programs should occur. (e) Control. Executive functions are needed to coordinate the processes of analysis, reformulation storage and production and to switch between the two active linguistic codes (Gile, 1997). Obviously, if the task is to be accomplished adequately, all these mental operations must be performed efficiently and WM has to work in a very efficient manner.

An important source of difficulty in interpreting is the simultaneity of comprehension and production (Christoffels and De Groot, 2005). Two streams of speech have to be processed simultaneously: the source language input has to be understood and the target language output has to be produced. Although interpreters exploit natural pauses in the source speech to facilitate their task (Barik, 1975), they must still speak and listen simultaneously about 70% of the time (Chernov, 1994).

An important question to be addressed is: How do the interpreters manage to cope with the adverse effects

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of concurrent articulation while trying to comprehend the source message? Research on WM has shown that the operations performed by the phonological loop are disturbed by the overt articulation of speech. If participants in a standard recall task are required to utter a string of irrelevant sounds (e.g. the word “the”), their recall is substantially impaired (Murray, 1965). This procedure is referred to as articulatory suppression and it is assumed to disrupt the processes of subvocal rehearsal and to prevent the normal refreshing of phonological information by the control articulatory process that is needed to maintain information in the phonological store (Baddeley, 1996).

If the articulation of output material during simultaneous interpretation is viewed as a process similar to the laboratory induced articulatory suppression, it should impose important constraints on the storage of input materials in the source language prior to recall. However, there is some evidence that experienced simultaneous interpreters are affected to a lesser degree by the demands of articulatory suppression compared to non-experts and students of interpretation. For example, Padilla, Bajo, Cànas and Padilla (1995) compared the effect of articulatory suppression on immediate and delayed free recall among experienced interpreters, second and third year interpretation students and a control group composed of highly competent professionals in language related disciplines. When participants studied under silent conditions, equivalent levels of recall were found for all the groups. However, when participants studied under articulatory suppression conditions, the professional interpreters showed a higher degree of recall compared to the remaining groups. In fact, while the students and control participants showed a significant decrement in recall in the articulatory suppression condition compared to the control condition, this effect was practically absent in the interpreter group. It is obvious that the recall of unrelated words under conditions of articulatory suppression is not equal to the simultaneous comprehension and production of large units of discourse. Simultaneous interpreting involves processing of large units of discourse rather than processing of unrelated words and the production of meaningful sentences rather than the production of meaningless repeated syllables. However, both situations share the simultaneity of language processing and production. In both conditions participants must process linguistic units while subvocal rehearsal in the articulatory loop is prevented by the concurrent articulation of linguistic units. Thus, although normal articulatory suppression conditions do not mirror simultaneous interpreting, the study of this effect in the interpreters can shed some light into the way in which they cope with the simultaneity of comprehension and production. The absence of articulatory suppression effects indicates that they learn to use their WM resources in a manner that permits them to avoid the deleterious effect of articulatory suppression. Probably, this special use also underlies their ability to comprehend and produce simultaneously. Therefore, if we find what this special use consists of, we will gain some understanding of the abilities required for simultaneous interpreting. In Experiments 1–3 we explored three possible WM functions that may be related to the absence of articulatory suppression effect in the interpreters.

In Experiment 1, we explored the role of WM storage capacity. An additional finding in the Padilla et al. (1995) study was that professional interpreters also showed a higher WM span compared to the students and control groups as measured by both standard digit and reading span tasks (Daneman and Carpenter, 1980). Thus, it was possible that the lack of articulatory suppression effect was related to the enlarged capacity of the interpreters that allowed them to cope with the demands of simultaneously understanding and producing. Hence, we introduced a silent and an articulatory suppression condition in a standard free recall task. We compared the interpreters’ recall with the recall of a group of participants that had the same WM capacity as the interpreters (high span individuals).

In Experiment 2, we explored whether the lack of articulatory suppression effects in the interpreters was due to an enhanced ability to coordinate processes and tasks. Interpreting requires the coordination of listening, reformulation and production processes. Due to the simultaneity of the interpretation task, the interpreter has to learn to distribute their resources among the various processes involved. Hence, this was a second possible factor contributing to the interpreters’ ability to cope with the simultaneity of comprehension and production. Thus, in Experiment 2 we explored the interpreters’ ability to perform dual tasks: Interpreters, high span individuals and control participants studied lists of words while they were tracking a moving point in a computer screen.

Finally, in Experiment 3, we explored whether the absence of articulatory suppression effect in the interpreters was due to knowledge specific factors. Research on expert performance has shown that the superior performance that the experts show in their area of expertise is related to the use of domain specific knowledge structures (e.g. Chase and Simon, 1973; Chi, Glaser and Rees, 1973). This has been related to the use of long term working memory structures (Ericsson and Kintsch, 1995) or to the storage of knowledge in the WM episodic buffer (Baddeley, 2000). Hence, in Experiment 3 we explored the role of domain specific knowledge in suppressing the effect of concurrent articulation. In the case of the interpreters, domain specific knowledge refers to word and language related knowledge. It is possible that they have richer representations of words in memory or that they access these representations more efficiently. In fact, some data indicates that the interpreters activate lexical
and semantic representations of words faster than other groups of participants (Bajo, Padilla and Padilla, 2000). Therefore, it was possible that the absence of articulatory suppression was due to the fast activation of word knowledge which provides support to the phonological loop. Therefore, in Experiment 3 we compared the interpreters’ recall of lists of L1 word, L2 words and nonwords under silent and articulatory suppression conditions.

Experiment 1

As indicated, the purpose of Experiment 1 was to explore the role of WM capacity in eliminating the articulatory suppression effect in the interpreters. Research on individual differences has shown that WM capacity and working memory executive functions are related to performance in a variety of complex tasks and skills such as comprehension (Just and Carpenter, 1980), spatial reasoning (Shah and Miyake, 1996) implicit learning (Reber and Kotovsky, 1997), reasoning and problem solving (Just, Carpenter and Hemphill, 1996). Although there is not a clear consensus about the nature of these differences (see Daneman and Carpenter, 1980; Engle, Kane and Tuholski, 1999; Towse, Hitch and Hutton, 2000 for conflicting interpretations), WM capacity seems to underlie performance in these complex cognitive tasks.

Recently, Christoffers, De Groot and Waldorp (2003) have reported data indicating that performance in simultaneous interpreting is significantly related to participants’ performance in a WM task. Although professional interpreters were not involved in their study, the participants were very proficient English/Dutch students. The results of the study indicate that WM span may underlie the ability to comprehend and produce in a simultaneous manner. Hence, the aim of Experiment 1 was to replicate the Padilla et al. study (1995) regarding the absence of articulatory suppression in the interpreters and to obtain direct evidence of the relation between WM capacity and the articulatory suppression effect. In Experiment 1, professional interpreters, psychology students of high WM capacity and control participants performed free recall tasks under silent and articulatory suppression study conditions. The predictions were simple: if the articulatory suppression effect directly depends on WM capacity, neither the professional interpreters nor the high span individuals should show decrements in recall under articulatory suppression, whereas participants in the control group should show normal articulatory suppression effects.

Method

Participants

Three groups of ten participants participated in the experiment. The first group was composed of professional interpreters; three of them had more than two years of professional experience and seven had just successfully passed their final interpretation exam at the University of Granada. The second group was composed of Psychology students; all of them were selected due to their high score in the Reading Span task (Daneman and Carpenter, 1980). The third group was composed of young professionals in language related studies (e.g. Law, History, Language and Literature). They were matched with the interpreter groups in their demographic characteristics (e.g. age, sex, academic success). Although they all had some knowledge of the English language, this knowledge was limited to very common words and very simple syntactic constructions, so they cannot be considered bilinguals.

In order to estimate the participants’ WM capacity and before participation in the actual experiments, a sample of 150 psychology students was asked to perform a Spanish version of the Reading Span test (Daneman and Carpenter, 1980). Phrase sets were shown to the participants. They were instructed to read each sentence aloud and to recall the last word of each sentence. The number of sentences in the set was increased gradually from two to six. The size of the largest set of sentences in which all last words were recalled correctly represented the participant’s memory span. Based on this estimation, ten students were selected for the high span group. The mean span for this group was 4.45 (SD = 0.49). Similarly, the interpreter and non-interpreter groups were asked to perform the reading span test. Their mean span was 4.30 (SD = 0.63) and 3.35 (SD = 0.91) respectively. Results of an Analysis of Variance (ANOVA) performed on the span data indicated that there were differences among the groups, F(2, 27) = 7.196, MSE = 0.494, p < 0.01. The differences between the interpreter and control groups and the high span and control groups were significant, F(1, 18) = 7.301, MSE = 0.618, p < .01, and F(1, 18) = 11.169, MSE = 0.541, p < .01, respectively. However, the interpreter and the high span groups did not differ from each other, F(1, 18) = 0.347, MSE = 0.323, p = .56.

Design

The design of the experiment was a 3 × 2 mixed factorial with groups (interpreters, high span individuals and control subjects) as a between group variable and study condition as a within participants variable (silent study vs. articulatory suppression).

Materials

Six lists of 16 words were constructed. Words were selected from Spanish norms (Algarabel, Ruiz and Sannmartin, 1988). Assignment of words to the lists was done so that the mean value of concreteness (5.2, SD = 1.21), word length in number of letters (5.8, SD = 0.83),
and frequency \((153.3, SD = 103.66)\) was equivalent for the six lists. Assignment of list to conditions was random.

**Procedure**

Participants were tested individually. Upon arrival, they were told that they were going to participate in a memory experiment and that their task was to try to recall as many of the words as possible from each of the lists that they were going to be presented. In the silent study condition, participants were told to concentrate and remember as many words as possible. In the articulatory suppression condition they were asked to overtly verbalize the syllable “bla” while they were studying the words. The order of presentation of the two conditions was balanced, so that across participants the silent and articulatory suppression conditions appeared equal number of times in the first and second positions. Participants received silent study or articulatory suppression instructions at the beginning of each block of three study lists and they were informed that they would perform the same task for all three lists. They were also informed that after each list, a message would appear on the screen indicating that they should recall the words from that list. This message remained on the screen for three minutes while participants wrote on a piece of paper as many words as they could recall from the list. After this period of time, a warning signal appeared on the screen for 3 s, after which a new study list was presented. Once the first block of three lists was presented, instructions for the silent or articulatory suppression conditions were given (depending on the balancing condition) and a similar study/recall list sequence was presented.

Words from each list were presented individually in the center of a computer screen and word order was randomized for each participant. The rate of presentation of the words was 3 s. To familiarize the participants with the rate of presentation, a practice list of five words was drawn up and presented to the participants before the start of the experimental list. In addition, in the articulatory suppression condition they received practice regarding the tempo of articulation, and the experimenter made sure that this tempo did not change when the study words were introduced.

**Results**

An ANOVA with study condition and trial (recall from each of the three lists) as within-participants variables and group as between-groups variable was performed on the data. Results of this analysis indicated that the effect of trial did not interact with any of the variables of interest, so we merged the data from the three trials. Thus, the mean percentage of recall for the three lists in each condition was calculated for each participant and taken as a single observation. A two-way ANOVA was carried out on the number of recalled words for each group and each condition. Results of this analysis indicated that the effect of group was not significant, \(F(2, 27) = 1.246, MSE = 11.551, p = .30\), however, the effect of study condition, \(F(1, 27) = 26.591, MSE = 2.513, p < .01\), and the interaction between group and study condition, \(F(2, 27) = 3.677, MSE = 2.513, p = .03\), were significant. As can be seen in Table 1, the mean recall for the articulatory suppression condition was lower than for the silent condition. However, simple effects analyses indicated that this was only true for the high span, \(F(1, 9) = 11.878, MSE = 4.770, p < .01\), and the control groups, \(F(1, 9) = 18.241, MSE = 1.450, p < .01\). The difference between the silent and articulatory suppression conditions was not significant for the interpreter group, \(F(1, 9) = 1.682, MSE = 1.320, p = .22\).

**Discussion**

Results of Experiment 1 indicated that expert interpreters were not affected by the overt articulation of an irrelevant syllable whereas high span and control participants showed normal articulatory suppression effects. The absence of articulatory suppression effect in the interpreter group replicates the results achieved by Padilla et al. (1995). In addition, the presence of this effect in the high span group indicated that the interpreters’ superiority in the articulatory suppression condition is not only due to their larger WM capacity. Both the interpreter and high span groups showed similar results in their performance in the reading span test. However, they were affected differently by articulatory suppression. In fact, the articulatory suppression effect was observed in both the high span and control group, even though their performance in the reading span test was significantly different. Therefore, although WM span may be related to the capacity to perform simultaneous interpretation (Padilla et al., 1995; Christoffels et al., 2003), it does not underlie the absence of articulatory suppression in the interpreter group and their ability to comprehend and produce simultaneously.
As indicated, several explanations have been offered for the correlation between high span measures and performance in complex tasks. In their original formulation, Daneman and Carpenter (1980) emphasized the trade-off between the processing and storage demands imposed on WM. From this point of view, the span task is a measure of the functional capacity of cognitive resources that could be flexibly allocated to processing and/or storage functions. Performance on WM span tasks reflects the amount of resources available after the processing requirements of the tasks are met. This view is compatible with the WM approach proposed by Baddeley (1996). Although WM span is supposed to be affected by storage variables such as the rate of articulation and time based forgetting (Towse and Hitch 1995; Towse et al., 2000), the efficacy of some executive processes (coordination, suppressing irrelevant information, activating long term representations, monitoring and so on) are also responsible for individual differences in WM capacity and the correlation between WM span and other measures of complex cognition. This relation would suggest that the absence of articulatory suppression in the interpreter group is not due to either the storage or the processing capacities of the interpreters.

However, recent papers (e.g. Miyake, Friedman, Emerson, Witzki and Howarter, 2000) suggest that WM executive functions may not be unitary in nature. Thus, although the span measures seem to be related to updating processes, performance in dual tasks (coordination function) is relatively independent from other executive functions such as updating, shifting or suppression. Hence, it is possible that the interpreters’ ability to process and recall information while they are engaged in overt articulation may be due to the efficacy of the coordination processes. Due to the conditions of simultaneity of the interpretation task, interpreters have to learn to distribute their resources among the various processes involved. In fact, part of the interpreters’ training is directed toward increasing their ability to divide attention between the input, the message that they are receiving and should interpret, and the output, the message that they convey. This training ranges from monolingual shadowing (repeating the message to which they are listening using several lags and sentences of increasing difficulty) to simultaneous interpretation. Therefore, the lack of articulatory suppression effects in the interpreters may be due to an enhanced ability to coordinate processes and tasks.

The purpose of Experiment 2 was to explore the interpreters’ general ability to coordinate processes and tasks. Thus, interpreters, high span and control participants performed a free recall task under normal or under visual tracking conditions. Visual tracking has been widely used to involve processing from the visual/spatial storage component of WM (Baddeley, Grant, Wight and Thomson, 1975; Baddeley and Lieberman, 1980). Therefore, the comparison of the participants’ performance in the dual and single conditions allowed us to assess the interpreters’ ability to coordinate verbal and visual tasks. If the absence of articulatory suppression in the interpreters is related to their capacity to perform dual tasks, we should find that the interpreters should outperform high span and control individuals in the visual tracking condition.

**Experiment 2**

**Method**

**Participants**

Participants from Experiment 1 also participated in this experiment. Thus, the experimental groups were composed of 10 professional interpreters, 10 psychology students of high WM span and 10 professional non-interpreters.

**Design**

The experimental design was a $3 \times 2$ mixed model with groups (interpreters, high span and control) as the between-group variable and study condition (single or dual) as the within-participants factor.

**Materials**

Six new lists of sixteen words, selected form Spanish norms (Algarabel et al., 1988), were constructed for this experiment. These lists were of the same characteristics as those used in Experiment 1. They were equated for their mean value of concreteness ($5.2, SD = 1.3$), word length in number of letters ($5.5, SD = 0.6$), and frequency ($175.7, SD = 113.0$). The assignment and balancing procedures were the same as those used in Experiment 1. Presentation of the study words was done auditorily through the use of Sony 200C headphones controlled by a PC computer.

**Procedure**

As in Experiment 1, participants were told that they were going to participate in a memory experiment and that their task was to try to recall as many of the words as possible from each of the lists that they were going to be presented. In the normal study condition, participants were told to concentrate and remember as many words as possible. In the visual tracking condition, they were told that they would have to perform two tasks simultaneously: study the words presented through the headphones while following a moving point on the computer screen with the mouse. Separate practice with the two tasks was given previous to the experiment. This practice consisted of the presentation of a short list of auditorily presented words for the free recall task and a one-minute performance for the tracking task.

In the tracking task, two horizontal lines appeared on the computer screen with a point moving along the
superior line. The point could move right or left but it appeared always on top of the superior line. The participants’ task was to follow the movements of this point with the computer mouse. To help the participants to anticipate the movements of the point, a curved line between the two horizontal lines indicated in advance the movements of the point. The distance between the two horizontal lines was 6 cm. The tracking task was designed with the Experimental Run Time System (ERTS) program (Beringer, 1995). This program was set to measure the average deviation between the point and the mouse movements. The participants were instructed to try to minimize the distance between these two points. As in Experiment 1, the order of the conditions was balanced across participants. The presentation of the study list was done auditorily at a rate of 3 s per word. The order of the words within the list was randomized for each participant. After each list, a message appeared on the screen indicating that the participants should recall the words from that list. This message remained on the screen for three minutes while the participants wrote on a piece of paper as many words as they could recall from the list. After this period of time, a warning signal appeared on the screen for 3 s, after which a new study list was presented.

Results

Tracking task
To capture possible individual differences in the tracking task, a preliminary analysis was performed. For this analysis, we calculated the mean deviation in millimeters between the point on screen and the point to which the computer mouse was moved for each participant in the tracking practice task (single performance in tracking). These means were introduced in an ANOVA with groups as between-participants’ variable. The results of this analysis indicated that there were differences among the groups, $F(2,27) = 3.583$, $MSE = 11.423$, $p = .04$. The results of planned comparisons indicated that the control group, composed of professional non-interpreters, had a significantly lower performance ($8.05$, $SD = 5.57$) than the interpreter group ($4.34$, $SD = 1.12$), $F(1,18) = 4.262$, $MSE = 16.152$, $p = .05$, and that they showed a marginal difference with the high span group ($4.80$, $SD = 1.40$), $F(1,18) = 3.206$, $MSE = 16.499$, $p = .09$.

Free recall
Since the three groups differ in their visual tracking ability an Analysis of Covariance was performed on the free recall data with groups as a between participants variable, study condition as a within subject variable and tracking performance as a covariate.1 The results of this analysis indicated that the effect of study condition was significant, $F(1,26) = 14.317$, $MSE = 2.152$, $p < .01$, but there were no group differences, $F(2,26) = 1.712$, $MSE = 5.404$, $p = .20$, and the interaction between group and condition was also non-significant, $F(2,26) = 0.451$, $MSE = 2.152$, $p = .64$. As can be seen in Table 2, the decrement in recall in the dual study and tracking condition was similar for the three groups of participants.

Dual tasking
To explore further the capacity to perform two tasks simultaneously, we performed an additional analysis taking into account performance on the secondary task (visual tracking). Following Baddeley, Della Sala, Gray, Papagno, and Spinnler (1997), we used the average proportion of decrements observed in performance from the individual tasks to the dual task, calculated by the following equation:

$$\left[ \frac{\text{Recall}_{\text{single}} - \text{Recall}_{\text{dual}}}{\text{Recall}_{\text{single}}} \right] + \left[ \frac{\text{Recall}_{\text{dual}} - \text{Recall}_{\text{dual}}}{\text{Recall}_{\text{single}}} \right]$$

For visual tracking, the single condition was calculated from performance in the 1 min practice task and the dual condition was determined from performance when participants were listening to the first list (approximately 1 min). Results of this analysis indicated that the differences among the groups were significant, $F(2,27) = 3.9$, $MSE = 0.14$, $p = .03$. Planned comparisons indicated that the high span group outperformed the control group, $F(1,18) = 4.9$, $MSE = 0.19$, $p = .03$, however the difference between the control group and the interpreters was marginal, $F(1,18) = 4.02$, $MSE = 0.17$, $p = .06$, and the difference between the high span group and the interpreters was not significant, $F(1,18) = 0.26$, $MSE = 0.5$, $p = .61$.

Discussion
Contrary to our predictions, the decrement in recall under dual task study conditions was similar for the interpreter and high span groups and for the interpreter and control

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1 The pattern of results of an ANOVA performed on the data was identical to those reported here.

### Table 2. Mean number of recalled words and standard deviations (in parenthesis) for each condition of Experiment 2.

<table>
<thead>
<tr>
<th>Group</th>
<th>Tracking</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interpreters</td>
<td>8.66 (1.36)</td>
<td>10.26 (2.19)</td>
</tr>
<tr>
<td>High span</td>
<td>9.73 (1.22)</td>
<td>11.50 (2.17)</td>
</tr>
<tr>
<td>Control</td>
<td>9.16 (2.00)</td>
<td>10.10 (2.34)</td>
</tr>
</tbody>
</table>
groups. The absence of differences in the ability to perform dual tasks between the interpreters and the two other groups seem to indicate that the interpreters’ ability to simultaneously comprehend and produce cannot be due to a general ability to coordinate simultaneous tasks. Visual tracking is supposed to involve processing from the visual/spatial storage component of WM (Baddeley et al., 1975), and although this component is probably not very much involved in interpreting, if the interpreters have developed their ability to coordinate different tasks, we would expect that they would also handle the requirement to coordinate the visual and verbal components of WM in a more efficient way. However, results from Experiment 2 indicated that this was not the case.

This lack of differences in dual tasking suggests that the absence of articulatory suppression effect in the interpreters is not related to a general capacity to coordinate processes and tasks, but possibly to a more specific ability to comprehend and produce simultaneously. This conclusion is in line with research on expert performance that shows that expertise is domain-specific (e.g. Walker, 1987; Ericsson and Smith, 1991).

Many studies have shown that experts and novices in a domain did not differ in their general aptitudes, but in their domain knowledge or skills (e.g. Chase and Simon, 1973; Chi et al., 1973). Thus, they have acquired declarative and procedural domain specific knowledge that permits them to circumvent the limits on their processing capacity. Recently, Baddeley (2000) has suggested that the episodic buffer, a system that permits integration of information from LTM and the storage components of WM, may be responsible for the superior performance of experts in their domain of expertise. The aim of Experiment 3 was to explore the role of domain specific knowledge in supporting the superior recall of the interpreters in the articulatory suppression condition.

A second interesting finding in Experiment 2 was the slight differences in dual tasking between the high span and the control group. This small effect contrasts with studies showing strong individual differences in dual tasking, especially in patients with WM deficits including frontal lobe lesions, Alzheimer’s and Parkinson’s diseases (Baddeley et al., 1997). The relative independence between performance in the reading span and dual tasks in Experiment 2 may be explained in two different ways: (a) As previously mentioned, some evidence suggests that WM executive functions may not be unitary in nature (Baddeley, 1996; Miyake et al., 2000). Hence, reading span and dual tasking may tap different executive processes. For example, Miyake et al. reported data indicating that the span measures are related to updating processes, whereas performance in dual tasks is relatively independent from other executive functions such as updating, shifting or suppression. (b) The difference in span between the high span groups (interpreters and high span students) and the control group was not of sufficient magnitude to show an effect. Thus, the mean span for the interpreters and high span group was 4.4 and 4.3 respectively, but the mean span of the control group was 3.3. This last score can be considered medium and therefore might not be a large enough difference with the high span group to capture possible differences in executive functions.

**Experiment 3**

The results of Experiments 1 and 2 indicated that the absence of articulatory suppression effect in the interpreter group cannot be solely explained by their larger WM capacity or by an enhanced ability to coordinate processes and tasks. Therefore, it is possible that the interpreters’ ability to comprehend and produce simultaneously is more specifically related to the efficient use of domain specific knowledge that permits them to cope with the high demands imposed on their storage capacity. Obviously, domain knowledge in the interpreters’ case refers to language-dependent long-term knowledge. In fact, part of the interpreters’ training concentrates on reinforcing their native language skills. Thus, some in-class exercises involve verbalising synonyms, providing related terms, closing (filling in the missing words in presented sentences), etc. The purpose of these exercises is to increase the speed of lexical and semantic access, not only so that the word is immediately understood, but also so that the form of the word is rapidly accessed allowing it to be quickly produced.

Recently, it has been suggested that familiarity with a language influences WM storage capacity. For example, Thorn and Gathercole (2001) examined language differences in memory span by comparing word and nonword recall accuracy in monolingual and bilingual individuals in French and English, while controlling the rate of articulation. Results indicated that both groups (monolingual and bilingual) showed superior recall performance for words and nonwords in their first language. This first language superiority was larger in the monolingual group. Similarly, monolingual studies show better immediate recall for words than nonwords (Gathercole, Pickering, Hall and Peaker, 2001) and for nonwords with a high degree of rated word likeness than for nonwords with very low ratings on a word likeness scale (Gathercole, 1995). These differences seem to indicate that long-term knowledge supports storage either by increasing the level of activation of information in the phonological loop or by providing information to reintegrate already decaying short-term representations (Thorn and Gathercole, 2001).

As mentioned before, the absence of articulatory suppression in the interpreters could also be related to language knowledge and language activation. It is possible that the interpreters’ ability to comprehend and produce
simultaneously is due to the support of long-term language specific knowledge. If this were the case, articulatory suppression effects should appear in the interpreter group if less familiar material were used (e.g. nonwords or words in their second language). The purpose of Experiment 3 was to explore this hypothesis. Thus, professional interpreters studied lists of Spanish words, English words or nonwords silently or under articulatory suppression conditions. If the presence or absence of the articulatory suppression effect was related to the support of long-term language specific knowledge, we would find no articulatory suppression effect in the translators’ first language (L1) and an articulatory suppression effect when nonwords were studied. Note that this support may come from the rich representation of words in the interpreters’ knowledge base, to their more efficient use of this knowledge or to both. Predictions for words in the second language (L2) were less obvious, since, although the interpreters were very highly competent bilinguals, they were unbalanced so that either Spanish (eight participants) or English (two participants) was their preferred language. The results of bilingual studies have shown directional effects on the translation of words. Translating from L1 into L2 is slower and more prone to errors than translating from L2 into L1 (e.g. Kroll and Stewart, 1994; Kroll, Michael, Tokowicz and Dufour, 2002), indicating larger familiarity and accessibility when L1 is involved. However, it is possible that, because of their training, both L1 and L2 are highly accessible (Christoffels, 2004).

Method

Participants

Twelve new professionals interpreters participated in the experiment: Ten of them were native speakers of Spanish and two were native English speakers, but had been living in Spain for more than 10 years. The mean WM span for this group was 4.25 (SD = 0.94).

Design

The experimental design was a 3 × 2 within-participant model. Both the type of study materials (words in L1, words in L2 or nonwords), and the study condition (with or without articulatory suppression) were manipulated within-participants.

Materials and procedure

A set of 64 Spanish words and their English translation were selected from Spanish and English norms (Algarabel et al., 1988; and Wilson, 1988, respectively). The Spanish and English words were equated in length, concreteness and frequency. The mean value for word length in number of letters was 5.72 (SD = 1.47) in Spanish and 6.19 (SD = 1.36) in English. The mean value for concreteness was 5.57 (SD = 1.40), and 513.73 (SD = 106.63), respectively. The mean word frequency was 256.44 (SD = 402.44) and 117.30 (SD = 149.78). For each participant, 32 of the words appeared in Spanish and 32 appeared in English. Within each language 16 words were randomly assigned to the articulatory suppression condition and 16 were assigned to the control condition. The English and Spanish word lists were constructed so that each word was presented only once (in one of the languages and in one of the suppression condition). However, across participants each word appeared an equal number of times in each language and suppression condition. In addition, each participant received two more lists composed of nonwords: One list was assigned to the articulatory suppression condition and the other to the control condition. Pronounceable nonwords were created by replacing a letter at random from a Spanish word. The nonword lists were constructed so that they were equivalent in length to the Spanish and English words. The mean value for nonword length was 4.81 (SD = 0.64). The balancing procedure was such that across participants the nonwords appeared an equal number of times in the control and articulatory suppression conditions.

Hence, each participant studied 6 lists, two in each type of study material condition (Spanish, English and nonword). Within each category of study material one list was studied under articulatory suppression condition and the other under normal study conditions. The order of presentation of each of the six conditions was balanced across participants. All other details of the procedure were identical to those of Experiment 1.

Results

The number of correctly recalled items was calculated for each participant and condition and submitted to an ANOVA with type of study material (L1 words, L2 words and nonwords) and study condition (articulatory suppression vs. control) as within participants factors. As indicated in the Participants section, ten of the participants were native Spanish speakers while two of them were native English speakers and English was their dominant language. Therefore, when analyzing the data the English words were considered L1 words for the two English speakers and the Spanish words were considered L1 words for the Spanish speakers. The results of the ANOVA indicated that the effect of type of study material was significant, F(2, 22) = 63.791, MSE = 4.672, p < .01. As can be seen in Table 3, participants recalled fewer nonwords than L1, F(1, 11) = 101.253, MSE = 3.975, p < .01, or L2 words, F(1, 11) = 97.426, MSE = 5.005, p < .01. The number of recalled words in L1 and L2 was statistically equivalent, F(1, 11) = 0.810,
Table 3. Mean number of recalled items and standard deviations (in parenthesis) for each condition of Experiment 3.

<table>
<thead>
<tr>
<th>Material</th>
<th>Articulatory suppression</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonword</td>
<td>3.0 (1.91)</td>
<td>4.6 (1.78)</td>
</tr>
<tr>
<td>Word L1</td>
<td>9.5 (2.11)</td>
<td>9.6 (1.87)</td>
</tr>
<tr>
<td>Word L2</td>
<td>9.3 (3.26)</td>
<td>11.0 (2.57)</td>
</tr>
</tbody>
</table>

MSE = 5.037, p = .38. The effect of the study condition was also significant, F(1, 11) = 8.422, MSE = 2.771, p = .01. Thus, participants recall was impaired by having to verbalize the syllable “bla” while studying.

Although the interaction between type of study materials and study condition did not reach significance, F(2, 22) = 1.076, MSE = 3.960, p = .35, inspection of Table 3 indicates, as predicted, that the difference between the articulatory suppression and the control condition was present when the participants studied nonwords and absent when the interpreters studied L1 or L2 words. Planned comparisons of the two study conditions for each of the study materials indicated that the difference between the suppression and control condition was significant when the study material consisted of nonwords, F(1, 11) = 5.259, MSE = 2.859, p = .04, it was marginally significant when the materials were L2 words, F(1, 11) = 3.956, MSE = 4.212, p = .07, and it was non-significant when the study materials were L1 words, F(1, 11) = 0.046, MSE = 3.621, p = .83. So we replicated the main result of Experiment 1, the interpreters’ recall was not affected by the concurrent articulation of a syllable. However, this was only true if the study material was composed of words in their native language. When nonwords were presented the articulatory suppression effect was significant. Interestingly, the L2 condition fell in between the other two conditions with a small marginal effect.

**Discussion**

Results of Experiment 3 indicated that the presence or absence of articulatory suppression effect in the interpreters is dependent on the familiarity of the materials. When the study material was composed of unfamiliar stimuli (nonwords), the effect was present. However, when the material was composed of familiar words in the interpreters’ native language, the effect was absent. Interestingly, when the interpreters were presented with L2 words, the difference between the articulatory suppression and the silent control condition was evident, but did not reach significance (so, it was an intermediate case between the unfamiliar nonwords and the familiar words in the interpreters’ L1 language).2

This pattern of results clearly indicates that word knowledge and/or the more efficient use of this knowledge by the interpreters provide support to the storage capabilities of the articulatory loop. This support may be especially important in conditions of blockage of the rehearsal system. Thus, although the concurrent articulation of irrelevant speech prevents the normal refreshing of phonological information by the subvocal rehearsal system, knowledge of the lexical/semantic properties of the words may act to redintegrate already decaying information. Although speculative, the episodic buffer proposed by Baddeley (2000) may be the WM subsystem providing this support.

**General discussion**

**Working memory, articulatory suppression and the interpreter’s ability to simultaneously comprehend and produce**

In the introduction we asked the question: how do interpreters manage to cope with the adverse effects of concurrent articulation while trying to comprehend the source message? In Experiments 1 to 3, we have explored different possible explanations by studying the articulatory suppression effect in different conditions. First, we tried to directly link the interpreters’ ability to simultaneously engage in language comprehension and production to their larger WM capacity. Previous studies have suggested that working memory capacity is related to the interpretation skills (Christoffels et al., 2003; Padilla et al., 1995). Thus, the interpreters’ show larger WM capacity than control professionals of high linguistic skills (Padilla et al., 1995) and WM capacity predicts interpreting performance (Christoffels et al., 2003). WM span has been interpreted as the ability to keep track of information while performing additional mental operations and it predicts performance in many complex operations.

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2 In Experiment 3, we did not include control groups because we were mainly interested in the presence or absence of articulatory suppression effects in the interpreters depending on the different language conditions. Therefore, we do not have an estimation of the possible changes in the effect on participants other than the interpreters. However, it was possible to predict either that the non-interpreters would show articulatory suppression effects of similar magnitude in the word and nonword conditions or that the magnitude of the effect was larger in the nonword condition. Any of these two possible outcomes would not change our interpretation that the absence of effect in the interpreters is related to the use of their linguistic knowledge. In addition, results of a pilot study in which we included high and low span participants that also varied in verbal fluency (as measured by their performance in a standard fluency task), indicated that regardless of their span and fluency all the participants showed articulatory suppression effects.
tasks. Therefore, WM capacity, the ability to cope with storage and processing demands, could also explain the lack of articulatory suppression effects in the interpreter group. Thus, we manipulated the study conditions (with or without articulatory suppression) in three groups of participants: interpreters, high span individuals and control participants. The predictions were simple, if the interpreters’ ability to cope with the simultaneity of comprehension and production was due to their large WM capacity; participants of similar capacity (high span individuals) should show this same ability and the concurrent articulation of a syllable would not have a detrimental effect on their recall. However, results of Experiment 1 indicated that while the interpreter group did not show articulatory suppression effects, the recall performance of the high span group was affected by the simultaneous articulation of a syllable. Therefore, although having a large WM capacity may be a necessary condition for good interpretation (see Christoffels et al., 2003), it is not sufficient to cope with the demands of simultaneous comprehension and production.

Second, we explored if the absence of articulatory effects in the interpreters was related to a general ability to coordinate processes and tasks. Coordination is supposed to be captured by the ability to perform dual tasks and it is related to frontal lobe executive functioning (Baddeley, 1996). For example, a neuroimaging study by D’Esposito et al. (1995) indicated that simultaneously performing a verbal task and a visuospatial task activates the prefrontal cortex in addition to the areas involved in processing verbal and visuospatial information. Thus, in Experiment 2, participants memorised lists of words while performing visual tracking. The predictions were again simple, if coordination was the process underlying the ability to simultaneously comprehend and produce, the interpreters would show a superior ability to perform dual tasks relative to the high span and control groups. However, the results indicated that the recall performance of the three groups was equally affected by the presence of a secondary task. In addition, when performance on the secondary task was also considered, the interpreter group did not show any superiority over the control medium span group indicating that general coordination cannot be the underlying process that explains the absence of articulatory suppression effects in the interpreters.

Finally, in Experiment 3 we explored the role of word knowledge in redintegrating information in the phonological store. Thus, we manipulated the type of stimulus presented for study (L1 words, L2 words and nonwords) and the study conditions (articulatory suppression and normal study). The results indicated that whereas the interpreters did not show articulatory suppression when L1 words were presented, articulatory suppression was clearly present when they had to study nonwords and they showed a small non-significant effect when studying L2 words. This pattern indicates that familiarity with a language plays an important role in the interpreters’ ability to comprehend and produce.

Long-term knowledge and articulatory suppression

Results from Experiment 1 to 3 suggest that the interpreters’ ability to cope with articulatory suppression is related to the use of long-term word knowledge rather than to an increased storage capacity or to a general ability to coordinate processes and tasks. The absence of articulatory suppression effects with L1 words and its presence with pseudowords is in agreement with suggestions that long-term knowledge provides support to the storage capacity of the phonological loop. The episodic buffer, the recently proposed component of working memory (Baddeley, 2000), may help in understanding how this support may take place. The episodic buffer is assumed to be a limited capacity system that binds information from a range of sources including long term memory representations. Although the exact relation between the episodic buffer and the phonological loop has not been clearly specified, it is reasonable to assume that when studying a list of words, participants store information in the phonological loop, but they would also use executive processes to activate phonological, lexical and semantic information from long-term memory and store them in the episodic buffer. This information would, in turn, be used to redintegrate the already decaying phonological information so that the study words can be recalled.

How do interpreters take advantage of the storage capacities of the episodic buffer? As previously mentioned, the exact relation between the articulatory loop and the episodic buffer has not been clearly specified and therefore a number of possibilities and questions are still open. First, what is the type of information in the episodic buffer that provides support to recall when concurrent articulation is required? Probably, in our experiments, a mixture of semantic and lexical/phonological factors supports recall. Phonological knowledge was probably involved because its effect seemed to be present when the phonological loop was involved (Experiment 1 and 3). However, this support was not evident when the secondary task was visual and the component involved was the visual/spatial sketch pad. In addition, word knowledge might also have a lexical/semantic component since the articulatory suppression effect was present when the study lists were composed of pronounceable nonwords, and it was reduced for L2 and absent for L1 words. This finding is consistent with studies that show better immediate recall for words than nonwords (Gathercole et al., 2001) and for nonwords with a high degree of rated word likeness than for nonwords with very low ratings in a word likeness scale (Gathercole, 1995).
Second, what type of transfer is enhanced in interpreters to allow them to cope with the demands of articulatory suppression? The redintegrative account stated above assumes that the phonological, lexical and semantic information recovered from long term memory and stored in the episodic buffer help to redintegrate the phonological forms of the words so that they can be recalled. The absence of articulatory effects in the interpreters could therefore be due to several factors. First, the greater availability of language specific long-term knowledge may help to activate and store information in the episodic buffer in a faster and more efficient way. As mentioned, part of the interpreters’ training concentrates on reinforcing their native language skills, so that lexical and semantic access is immediate. Consistent with this, there is some evidence of a relationship between experience in simultaneous interpretation and efficient language processing. For example, Bajo et al. (2000) compared the performance of interpreters, students of interpretation, bilinguals, and professionals from other fields on a categorization task. They showed that interpreters categorized non-typical exemplars of the categories faster than the students and the bilinguals. This finding indicates faster semantic access in the interpreters than in other participant groups. However, it is also possible that part of the interpreters’ superiority in coping with articulatory suppression may be due to information being transferred from the phonological store to the episodic buffer in a relatively faster way. Individuals who are faster in transferring information from the phonological store to the episodic buffer would also have an advantage when articulatory suppression is involved. Although our data suggest that the availability of language information underlies the interpreters’ superiority, it is also possible that transfer from the phonological store to the episodic buffer is also enhanced in the interpreters. Further research should clarify this issue.

Language interpretation and expertise

The present account of the interpreters’ superiority is also in agreement with research on expert performance that shows that experts and novices in a domain did not differ in their general aptitudes, but in their domain knowledge or skills (e.g. Chase and Simon, 1973; Chi et al., 1973). This knowledge permits them to circumvent the limits on their processing capacity (Ericsson and Kintsch, 1995; Baddeley, 2000). Thus, the results of Experiments 1 and 2 suggest that one of the greater sources of difficulties in the interpretation task, the simultaneity of comprehension and production, cannot be circumvented by only a large working memory capacity or by an enhanced general coordination process, but by specific knowledge related to the interpreters’ skill (language specific knowledge).

It is interesting that although the results of Experiment 2 suggest that the interpreters are not better in dual tasking than control individuals, other experiments indicate that they are better at coordinating verbal tasks. Thus, Padilla (1995) had interpreters and professionals from other fields perform a relatedness task while they memorized words. Participants were simultaneously presented with three words: one in the left ear, another in the right ear and another on the computer screen. They had to respond as fast as possible if the words presented on the computer screen and the right ear were semantically related and at the same time, they had to listen to the words in the left ear and memorize those that corresponded to the name of an animal for further recall. They performed the two tasks (memorize and judge the relationship between words) either singly or simultaneously. The results indicated that the interpreters outperformed the control group in the dual task condition. Both the recall of the animals and the speed and accuracy of the relatedness task were better for the interpreters than for the control group in the dual task condition, indicating that they were superior at coordinating the two tasks. Hence, when the two tasks involve linguistic information their language specific skills may also support coordination. This again is consistent with data showing that experts’ specific knowledge and skills support performance in complex tasks. Thus, although the interpreters are better able to coordinate language related tasks, their performance suffers as much as that of other individuals when non-specific tasks are involved.

It is important to notice here that because of the characteristics of the control groups used in these experiments we cannot claim that the interpreters’ ability to process linguistic units while articulating is due to the training process and to the tasks demands involved in interpreting. Because our control groups did not include bilinguals and students of interpretation, we cannot rule out that the interpreters’ results are not due to their knowledge of multiple languages or to self-selection (i.e. only individuals with certain cognitive skills end up working as interpreters). However, results of previous studies (Padilla et al., 1995; Bajo et al., 2000) suggest that training may underlie the interpreters’ superior performance in WM and language related tasks. In these studies, students of interpretation were compared to professional interpreters and non-interpreters control. These students were selected because they had already finished their first year of general translation studies, they were starting their training in interpretation, and they all had very good knowledge of at least two languages. Because of the difficulty of the task very few students of translation specialised in language interpretation, but the percentage of success of these students is around 80%. Interestingly, results indicated that the students showed normal articulatory suppression effects and they did not differ from non-interpreters.
controls on their WM span and other language related tasks. In addition, Chincotta and Underwood (1998) reported results that indicate differences in WM processes between English-Finnish interpreters and Finish students majoring in English. Although, they did not find differences in digit span or articulatory suppression effects between the two groups of participants, the standard language effect in the digit span (a larger digit span in the language in which one can articulate faster) disappeared for the students in an articulatory suppression condition, whereas for the interpreters did not change as a function of the articulatory condition. However, further research using longitudinal designs is needed to make this point stronger.

In conclusion, our studies suggest that language related knowledge supports recall under articulatory suppression conditions. It is likely that the interpreters’ training in language related skills helps them use the episodic buffer in a more efficient way. Further research should clarify the exact form in which this support is provided.

References


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