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# Working memory resources and interference in directed forgetting

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Recent research has shown that the ability to inhibit irrelevant information is related to Working Memory (WM) capacity. In three experiments, we explored this relationship by using a list-method directed-forgetting task (DF) in participants varying in WM capacity. Contrary to predictions, in Experiment 1, DF effects were only found for participants with low WM capacity, whereas high WM capacity participants did not show this effect. This unexpected pattern of results was explained as due to the differential susceptibility to interference of high and low span participants. In Experiments 2 and 3, interference was increased by introducing a memory load between the to-be-forgotten and the to-be-remembered list (Experiment 2) and by increasing the list length (Experiment 3). In these conditions of high interference, the pattern of results was reversed so that DF effects were obtained for the high span group and they were not present for the low span group. The reversal of the effect for the high and low WM capacity group depending on the degree of interference suggests that inhibition in the DF procedure depends on both: the degree of interference experienced by the participants, and the availability of controlled resources.

Recent research has emphasized the importance of inhibitory processes in cognition (Anderson, 2003; Kane & Engle, 2000; Lustig, Hasher & Tonev, 2001). The ability to pay attention to relevant goals and information and to suppress those that are irrelevant for the task plays an important role in many complex situations. The empirical evidence suggests that the ability to inhibit irrelevant information improves across childhood and early adolescence (Lechuga, Moreno, Pelegrina, Gómez-Ariza, & Bajo, 2006; Harnishfeger, & Pope, 1996; Wilson & Kipp, 1998; but see Zellner &

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Bäuml, 2005); and it is reduced in older adults (Lustig et al., 2001; Zacks, Radvansky & Hasher, 1995; but see Zellner, & Bäuml. 2005).

The ability to inhibit irrelevant information has been investigated by using the directed-forgetting (DF) task. In a DF task, participants are presented a series of items. Following a cue, they are instructed to forget some of these items (the to-be forgotten items, TBF) and to remember the rest of them (the to-be-remember items, TBR). At recall, participants are instructed to try to recall the words from the two lists. A directed-forgetting effect is evidenced by a decrement in recall of the TBF items in comparison with the TBR items.

Two different methods have been used to elicit the DF phenomenon (see Basden & Basden, 1998, for a review of methods in DF). In the item method, participants are presented to items that are cued for either remembering or forgetting. They are told that they will be required to remember only the remember-cued items. The evidence suggests that the reduced recall of TBF items with this method is the result of differential encoding of items. Individuals may spend less time and cognitive effort encoding the TBF items relative to the TBR items. The TBR items receive more extensive rehearsal than the TBF items, resulting in better storage and retrieval.

In the list-method DF task, participants are presented with a set of items to be studied for later recall. After presentation of the first list, participants in the forget condition are instructed to forget the items they have just learned (TBF items). Following these instructions, a second list is presented, and participants are required to learn these new items. At recall, they are asked to remember the items from both lists. As a control, in a remember condition, participants are presented the two lists and are instructed to remember both. That is, participants in the remember condition also learn the two lists but they are not instructed to forget the first before presentation of the second list. Typically, participants in the forget condition remember fewer TBF than TBR items. Also, in the forget condition participants remember fewer List 1 items than participants in the remember condition.

It has been argued elsewhere (Basden & Basden, 1998; Bjork & Bjork, 1996; Conway, Harries, Noyes, Racsmany, & Frankish, 2000) that directed forgetting effects with the list method are the result of retrieval inhibition. Retrieval inhibition is believed to operate by reducing the accessibility of the TBF items in long term memory. The instructions to forget, following the presentation of the first list of items, trigger inhibitory processes that decrease the accessibility of these items, although they remain available, because they have been encoded and stored in long term memory. Evidence in support of this idea comes from the finding that the directed forgetting effect with the list method is not observed on recognition tests (but see Sahakyan & Delaney, 2005), whereas this effect is usually found on both recall and recognition tests when the item method is used. Similarly, re-exposure to the TBF items decreases dramatically DF effects with the list method, but not with the item method (Basden, Basden & Wright, 2003; Bjork & Bjork, 1996). These findings provide support to the conclusion that different cognitive mechanisms underlie DF effects in the two methods and that retrieval inhibition is responsible for DF effects in the list method (but see Sahakyan & Delaney, 2005 for a contextually based explanation of the effect).

Further support comes from experiments that have studied the conditions that constrain the DF effect in the list method. A critical condition for retrieval inhibition to occur is the presence of new material to learn after the forget instruction (Bjork, 1989). That is, the instructions to forget are not a sufficient condition to lower the accessibility of the TBF items; rather, the presentation of a new set of items to be learned is completely necessary for inhibition of the TBF items to occur. According to Conway et al. (2000), this new learning is necessary because it provides an opportunity to focus attention on items other than the TBF items, and this competition for attention would be the critical factor that triggers inhibition. When the two lists are strongly associated (Conway et al., Experiment 6) the DF effect is completely abolished, indicating that inhibition of the TBF items depends on the presence of competition between the TBF and the TBR lists. In addition, performing a secondary task during the learning of the second list reduces, or even eliminates, the inhibition of the first list of items (Conway et al., Experiments 2, 3 and 4), suggesting that inhibition of the TBF items is also dependent on the availability of attentional resources during the learning of the second list. In summary, three conditions seem to be necessary for inhibition to occur in the DF procedure: 1) The intent to forget induced through the instructions; 2) The storage of new competing information; and 3) The availability of cognitive resources during the new learning phase.

However, there are still many questions regarding inhibition in the DF procedure that need to be answered. Some of these questions refer to the controlled nature of this inhibitory process, and to the parallels between retrieval inhibition and the inhibitory mechanism that works in attention related task (Anderson, 2003; Levy & Anderson, 2002). As Bjork (1998, p. 457) puts it, "The issues of control, intent, and resource allocation are among the important remaining issues in the study of directed forgetting in humans".

In order to address some of these issues, in Experiments 1, 2 and 3, we investigated individual differences in the magnitude of the DF effect, and the relationship between these differences and working memory (WM) capacity. A number of studies have provided evidence that relates WM capacity to the efficiency of inhibitory processes. This relation has been shown in different paradigms, such as paired-associated learning tasks (Rosen & Engle, 1998), antisaccade tasks (Kane, Conway, Bleckley & Engle, 2001), the "cocktail-party" phenomenon (Conway, Cowan, & Bunting, 2001), the STROOP task (Long & Prat, 2002) or interference paradigms (Kane & Engle, 2000; Soriano, Macizo & Bajo, 2004). The results of these studies indicate that individuals of high WM capacity perform better than individuals of low WM capacity in tasks where inhibition is supposed to be involved. In fact, some authors (Lustig et al., 2001; Zacks & Hasher, 1994) have argued that differences in inhibitory processes underlie individual differences in working memory. Inhibition controls access to working memory, suppressing both distracting information and no-longer-relevant information. In a similar vein, Engle and colleagues (Engle, Kane & Tuholski, 1999) have proposed that WM capacity is determined by the capability to use controlled attention to prevent interference. From this view, inhibition is a product of controlled resources, and group differences in inhibition may result from differences in controlled attentional resources (Engle, Conway, Tuholski & Shisler, 1995).

The focus of Experiment 1 was to examine the relationship between WM capacity and the magnitude of the inhibition observed in a DF task. If the process of retrieval inhibition is similar to the inhibition that occurs in other cognitive domains (i.e. selective attention) we would expect to observe a close relationship between WM capacity and retrieval inhibition. Thus, we would expect large and reliable DF effects in individuals of high WM capacity. In contrast, we would predict that these effects would be reduced, or even abolished, in individuals selected by their low WM capacity.

In Experiment 2 and 3, we will address the role of competition in producing retrieval inhibition and its possible interaction with WM capacity and cognitive resources. Thus, in Experiment 2, we introduced a six digit memory load between list 1 and 2. High and low WM capacity participants were instructed to keep the six digits in memory while studying list 2. The presence of this memory load would have two consequences: 1) Increase competition and, 2) reduce the amount of WM resources while learning List

2. In Experiment 3 competition was increased by increasing the number of words in List 1.

## EXPERIMENT 1

As mentioned above, the purpose of the first experiment was to explore the relationship between WM capacity and the inhibition observed on a list DF task. To this end, we screened participants for WM capacity using the Daneman and Carpenter's (1980) reading-span task. High and low span individuals were asked to return for a second session. In the second session, they performed a list DF task. We predicted that inhibition of the first list in the forget condition would be greater for high span individuals than for low span individuals. This prediction follows from two assumptions: 1) Inhibition is controlled in nature and, therefore, depends on the amount of controlled resources (Anderson, 2003; Levy & Anderson, 2002), and 2) Individual differences in WM capacity are in part due to differences in controlled attentional resources (Engle, Kane & Tuholski, 1999).

### METHOD

**Participants**. The participants were undergraduate students from the University of Granada who received course credit for their participation. Thirty two participants were selected to compose the low and high working memory span groups. These participants were selected from a larger pool who had received the Daneman and Carpenter's (1980) reading-span task: sixteen participants were selected from the top third of the distribution of the reading-span scores (high span group) and sixteen were selected from the bottom third (low span group). The averaged span values for the low and high span groups were 2.06 and 3.78, respectively. The difference in span between the two groups was significant, $F$ (1, 30) = 144, $MS$ = 23.63, $p < .001$.

**Design**. The design was a 2 x 2 x 2 mixed design, with WM Span (high and low) as a between-subjects variable, and instructions (remember and forget) and list (1 and 2) as within-subjects variables.

**Procedure and Materials.** The experiment was conducted in two sessions. Between 1 and 7 days intervened between the two sessions. Participants were tested individually on both sessions.

In the first session, participants performed a Spanish version of the reading-span task (Daneman & Carpenter, 1980). This task was composed of 70 unrelated, complex sentences (25 were used for practice). These sentences were randomly assigned to create five sets of two sentences each, five sets of three sentences, five sets of four sentences, and five sets of five sentences. For example, participants were presented with sentences such as:

> *“El cuerpo fue descubierto por María, que acudió a la finca a visitar a unos familiares”*
>
> *“Ahora se escriben tratados u obras científicas donde todo se pone en tela de juicio”.*
>
> *“Ocho puertas grises de madera enferma cerraban los ocho apartamentos de cada rellano”.*

and participants would have to remember “*familiares, juicio, rellano*”.

The sentences were presented one at a time in the centre of a computer screen, and participants were required to read the sentences aloud while trying to remember the last word of each sentence in the set. As soon as a sentence was read, the experimenter pressed a key and another sentence was presented. This procedure continued until a black screen signalled the end of the set and indicated that the participant had to recall the last word of each of the sentences. Participants were presented with increasingly longer sets of sentences until they failed three out of five sets at a particular level. A participant’s score was equivalent to the highest set size at which they correctly recalled all the final words for three out of the five lists. In addition, half a point was added to the final score if they recalled all of the final words for two of the five lists at that set size.

Only those participants who scored in the top third of the distribution (high span group) or in the bottom third of the distribution (low span group) were asked to participate in the second session. In the second session, participants performed two DF tasks, with an interval of 10 minutes between them. The tasks were identical to those used by Conway et al. (2000). Four lists of 10 words were constructed. These 40 words were drawn from Alameda & Cuetos (1995), and they were selected so that they all have medium to high frequency and they all were two to three syllables length. Assignment of words to tasks and lists was randomised for each participant. The order of presentation of the words within each list was also random.

In the Remember DF task, participants were asked to learn a list of 10 unrelated words. Words were displayed on a computer screen, one at a time for 2 s with a 2 s interitem interval. Following the presentation of the first list, participants were told that a second list would be presented and that they would have to recall the words from the two lists later. Then participants were instructed to press the space bar to initiate list 2 presentation. Prior to recall, participants were shown a three digit number and they were required to count backward by threes for a minute. After this, participants were given a sheet of paper and were asked to free recall as many of the words as they could from both lists.

In the Forget DF task, the same procedure was followed, except for the instructions between the two lists. Participants were informed that the list they had just seen "was just a practice list to familiarise you with the presentation rate and type of word"; they were asked to forget them and to remember only the next list, which was the *real experimental* list that they would have to recall later. At recall, they were asked to recall all of the words they were presented, even the words they had been told to forget.

The order of presentation of the tasks was counterbalanced across participants, so that half of the participants performed the forget-DF task first and half of the participants the remember-DF task first. The lists were counterbalanced across tasks, and words were randomly allocated to the lists in each task.

## RESULTS AND DISCUSSION

Although tasks order was counterbalanced, we performed a 2 (WM Span) x 2 (Tasks Order) x 2 (Instruction) x 2 (List) ANOVA on the proportion of recalled words to make sure that the order of the tasks was not influencing the results. The results of this ANOVA indicated that task order did not have a significant effect on the number of words recalled, $F$ (1, 28) = 3.42, $MS$ = .29, $p$>.05, and it did not interact with any other variable (all $p$>.05). Thus, because of the absence of interactions, the data were collapsed and this variable was not considered any further.

Table 1 shows the average recall proportions and standard deviations for each condition of the experiment. In this and all other experiments two Analyses of Variance (ANOVAs) were performed on the data: one for the DF-Remember task and the other for the DF-Forget task. In addition, whenever a significant DF effect was found (List 1 recall < List 2 recall in the forget condition), we performed comparisons between the recall of List 1 in the forget condition and the recall of Lis1 in the control condition and between the recall of List 2 in the forget condition and the recall of List 2 in the control condition. These two comparisons are important because they help to clarify the source of the DF effect. Thus, the first comparison would reflect the *cost* of inhibition (List 1 in the forget condition is recalled worse than List 1 in the control condition as a result of retrieval inhibition). In contrast the second comparison reflects the *benefits* of inhibition (List 2 in the forget condition is recalled better than List 2 in the control condition because retrieval inhibition of List 1 in the forget condition reduces the amount of proactive interference acting on List 2). Finally, we performed correlations between WM capacity and individual DF scores.

**Table 1: Proportion of correct recall and standard deviations (in brackets) for each condition of Experiment 1.**

| | | Remember Task | Forget- Task |
|---|---|---|---|
| High Span | List 1 | .44 (.06) | .49 (.06) |
| | List 2 | .44 (.07) | .60 (.05) |
| Low Span | List 1 | .44 (.06) | .27 (.06) |
| | List 2 | .44 (.07) | .53 (.05) |

*Control-Remember Task*.- A 2 (WM Span) x 2 (List) ANOVA was performed on the proportion of words recalled in the Remember task. This analysis revealed that neither the main effects (WM Span or List effects) nor the interactions were significant (all $F$s < 1). Thus, High and Low Span individuals showed similar patterns of recall when instructions to forget were not provided.

*DF-Forget Task*- A 2 (WM Span) x 2 (List) ANOVA was conducted on the proportion of words recalled. A main effect of WM Span was found, $F$ (1, 30) = 5.35, $MS$ = .32, $p$ = .03, indicating that the high span participants recalled more words than the low span participants. A main effect of List was also found, $F$ (1, 30) = 14.21, $MS$ = .54, $p$ = .001; more words were recalled from List 2 than from List 1, reflecting the effect of instructions to forget List 1. The interaction Group x List did not reach significance, $F$ (1, 30) = 2.16, $MS$ = .83, $p$>.05. However, as we had clear predictions about the pattern of recall for the high and low span individuals, we conducted further analyses for each span group separately.

The analyses of simple effect revealed that the low span participants recalled more words from List 2 than from List 1, $F$(1, 30) = 13.72, $MS$ = .53, $p$<.001, showing a reliable DF effect. In contrast, the difference between the number of words recalled from List 1 and List 2 by the high span participants did not reach significance, $F$(1, 30) = 2.64, $MS$ = .10, $p$>.05. This result indicated that the small DF effect shown by the high span participants was not reliable.

To further understand the DF effect observed for the low span participants we performed additional analyses. First, we compared the proportion of recall for List 1 in the control and forget condition. This comparison indicated that the low span participants recalled more List 1 items in the control than in the forget condition ($p$ = .05). This effect reflects the cost of forgetting on List 1. Second, we compared the proportion of recall of List 2 for the control and forget condition. This comparison indicated that the low span participants recalled more List 2 items in the forget condition than in the control condition ($p$ = .04). This difference reflects the benefits of direct forgetting, that is, inhibition of List 1 reduces the amount of proactive interference and produces better recall of List 2. Therefore, the DF effect shown by the low span participants was evident when we analysed both the costs and benefits of the forgetting instructions. Finally, we performed a correlation between WM span and DF scores. Thus, for each participant we calculated a DF score by subtracting the proportion of recall for List 1 and List 2 in the forget condition. The results of this analysis indicated that this correlation was close to significance ($r$ = - .30, $p$ = .09). The negative sign of the correlation is consistent with the results obtained in the ANOVA by indicating that participants with larger WM capacity showed smaller DF effects.

Based on the literature relating WM capacity and inhibition, this pattern of results was surprising and unexpected. If WM capacity is related to more efficient inhibitory control, the DF effects should have been larger and more robust in the high span individuals than in the low span participants. However, we observed the opposite pattern: reliable DF effects for the low span participants and small non-reliable DF effects for the high span participants. Is retrieval inhibition different to those inhibitory processes that are directly related to WM capacity? What is the reason for the inverse relationship found in Experiment 1?

In order to understand this unexpected finding, we returned to the critical conditions for the DF effect to occur. As mentioned, the presence of new list to learn is critical for DF to occur, that is, the presence of competition is crucial to trigger inhibition: "*The strength of the inhibition is set by the potential degree of competition (…); the more the potential of the TBF materials to compete later in recall with the TBR materials the greater the degree of inhibition*" (Conway et al., 2000, p. 426). When competition is reduced (for example, by increasing the integration of items), inhibition is disrupted or even abolished (Anderson & McCulloch, 1999). Competition has usually been manipulated by varying the materials, for example, the similarity of the lists (Conway et al., 2000). This type of manipulation is based on the assumption that competition is dependent on the materials to be learned, and independent of the individuals who learn them. In our view, however, the degree of competition should not be considered as a stable property of the materials but as a consequence of the interaction between the materials to be learned and the individuals that learn it. Thus, given the same learning materials, the high span individuals may experience less interference than the low span individuals so that inhibition of List 1 may not be necessary to them. In contrast, low span individuals may experience greater amounts of interference, and this interference may *trigger* inhibition of List 1. Indeed, a large body of evidence has shown that low span individuals are more vulnerable to memory interference than high span individuals (Kane & Engle, 2000; Rosen & Engle, 1997).

The small unreliable DF effect for our high span participants is consistent with this proposal. If inhibition depends on the degree of interference and competition, it is possible that learning two lists of ten unrelated words does not produce enough interference to trigger inhibition in the high span group and therefore, DF effects were not present. However, the same set of materials may produce greater interference for low span individual, so that inhibition was triggered and DF effects appeared.

In Experiments 2 and 3, we try to explore this hypothesis by increasing the degree of competition. We predicted that this manipulation would differentially affect high and low span individuals. If the lack of inhibition of List 1 for high span participants was due to the fact that they experience smaller degrees of interference, then increasing competition may produce DF effects in this group. On the contrary, increasing competition would suppose a cognitive overload for low span individuals, and this may disrupt inhibition of List 1. It is important to keep in mind that these predictions are based on a set of assumptions: 1) Inhibition and DF effects depend, in part, on the individual experiencing large enough degrees of competition; 2) High WM individuals experience less interference than low span individual; 3) Inhibition also depends on the availability of cognitive resources in the moment in which inhibition has to be applied. Inhibition itself is capacity consuming, if the task consumes many resources, it is possible that very few of them would be available for efficient inhibition. In agreement with this last assumption, Macrae, Bodenhausen, Milne, & Ford (1997), and Conway et al. (2000) found that when participants performed a secondary task during the study of List 2, the DF effect was abolished. Conway et al. argued that the attentional demands of performing a secondary task prevented participants from inhibiting List 1. Thus, if competition is increased, learning the items may channel most of the cognitive resources for low span individuals and DF effects may not be found.

Thus, we predicted that increasing competition would lead to results different from those observed in Experiment 1. That is, we would observe DF effects in high span individuals and no effects for low span individuals.

## EXPERIMENT 2

The purpose of Experiment 2 was to examine the hypothesis that DF effects depend on both the degree of competition and the amount of available cognitive resources. To this end, we used the same DF procedure as in Experiment 1, but introduced a six-digit memory load between the two lists. The purpose of introducing this memory load was to increase the demands for cognitive resources while studying List 2. We expected that the additional memory load would have different consequences for the two groups of participants. Adding new interfering items would increase the amount of competition for both the high and low span participants, so that inhibition would be triggered for both groups. But, to the extend that inhibition depends on the amount of available WM resources, the presence of inhibition (and DF effects) may depend on the span of the individuals. Thus, inhibition could still act for the high span group, since high span is related to larger WM resources, but it may be abolished or reduced for the low span individuals due to an overload of their WM resources.

### METHOD

**Participants.** The participants were undergraduate students from the University of Granada who received course credit for their participation. Forty new participants were selected based on their scores on the reading span test (see procedure above). Twenty participants were selected from the top third of the distribution of the reading-span scores (high span group) and twenty were selected from the bottom third (low span group). The averaged span values for the high and low span groups were 2.07 and 3.9, respectively. The difference between the groups was significant, $F$ (1, 38) = 141.6, $MS$ = 33.31, $p< .05$.

**Design.** The design was identical to that described in Experiment 1.

**Procedure and Materials.** The procedure and materials were identical to those described in Experiment 1, except for the memory load presented between the lists. For both the Remember and the Forget task, after receiving the instruction (to remember or to forget), a list of six randomly selected digits appeared for 20 seconds on the computer screen.

Participants were instructed to learn it. After the 20 s elapsed, participants were instructed to press the space bar to initiate the display of the second list. Following presentation of List 2, participants were required to write in a piece of paper the list of digits. Then they were told to perform the filler task and, immediately after, they were asked to recall as many of the words as they could from both lists.

## RESULTS AND DISCUSSION

The average recall scores and standard deviations for each condition are presented in Table 2. As in Experiment 1, we report the analysis of the Remember task first followed by the analysis of the Forget task. For both tasks, the data from the participants who could not report the digit list exactly were excluded from the analysis. Data from 3 high span participants and from 4 low span participants were excluded.

**Table 2: Proportion of correct recall and standard deviations (in brackets) for each condition of Experiment 2.**

| | | Remember Task | Forget- Task |
|---|---|---|---|
| High Span | List 1 | .47 (.04) | .36 (.05) |
| | List 2 | .37 (.05) | .60 (.05) |
| Low Span | List 1 | .38 (.04) | .36 (.05) |
| | List 2 | .27 (.05) | .39 (.05) |

*Control-Remember Task*.- A 2 (WM Span) x 2 (List) ANOVA was performed on the proportion of recalled words in the Remember task. This analysis revealed that the main effect of List was significant, $F$ (1, 31) = 5.87, $MS$ = .18, $p$<.05. More words were recalled from List 1 than from List 2, probably reflecting a proactive interference effect. The effect of Group, $F$ (1, 31) = 2.91, $MS$ = .14, $p$>.05, and the interaction Group x List, ($F$<1), were not significant. As in Experiment 1, the high and low Span individuals showed similar patterns of recall when instructions to forget were not provided.

*DF-Forget Task*.-A 2 (WM Span) x 2 (List) ANOVA was conducted on the proportion of words recalled in the Forget task. The main effect of WM Span approached significance, $F$ (1, 31) = 3.46, $MS$ = .17, $p$ =.07. The high Span participants tended to recall more words than the low span participants. The main effect of List was significant, $F(1, 31) = 8.46$, $MS = .29$, $p = .007$; More words were recalled from List 2 than from List 1 reflecting a DF effect. Interestingly, the interaction WM Span x List was significant, $F(1, 31) = 5.14$, $MS = .18$, $p = .03$.

Planned comparisons revealed that this interaction was caused by the opposite pattern that we had observed in Experiment 1. In this case, high span participants recalled significantly more words from List 2 than from List 1, $F(1, 31) = 12.99$, $MS = .45$, $p = .001$. In contrast, there was no difference between the number of words recalled from List 1 and List 2 for the low span participants, $F<1$. As predicted, the DF effect was only observed for the high span group and not for the low span group.

As in Experiment 1, we performed costs and benefits analyses to better understand the observed DF effect. Thus, the comparison of Lis1 for the control and forget conditions for the high span group indicated that participants tended to recall fewer items in the forget condition relative to the control condition ($p = .08$; *cost* of forgetting) and that they recalled more List 2 items in the forget than in the control condition ($p = .001$; *benefits* of forgetting). Finally, as in Experiment 1, we performed a correlation between WM span and DF scores. Again, for each participant in Experiment 2 we calculated a DF score by subtracting the proportion of recall for List 1 and List 2 in the forget condition. The results of this analysis indicated that although this correlation did not reach significance ($p = .11$), the positive sign of the correlation ($r = 0.27$) suggested that participants with larger WM capacity also showed larger DF effects.

Hence, consistent with our predictions, retrieval inhibition seems to be dependent not only on the amount of interference produced by the material, but also on individual differences in susceptibility to this interference. These individual differences seem to be related to WM capacity.

In summary, the results of Experiment 1 showed a reliable DF effect for the low span group, and a small unreliable DF effect for the high span group. We interpreted this unexpected finding in terms of the relationship between interference and inhibition. We argued that the high span participants experienced relatively less interference than the low span participants, and this smaller interference was the main reason for the reduced DF effect in this group. Evidence from Experiment 2 supports this proposal. Introducing a memory load between the two lists reversed the pattern found in Experiment 1, so that a DF effect was found for the high span group and it was not found for the low span group. The increase of interference produced by the six digit memory task triggered inhibition for the high span group. In contrast, because of their smaller memory capacity, the increase in interference may have overloaded the cognitive resources for the low span groups so that they may have not been able to trigger inhibition. In Experiment 3 we aimed to replicate and extend these findings by increasing competition through the use of new longer lists. Participants were presented with lists of 15 unrelated items, hence, the degree of interference in Experiment 3 should be larger than in Experiment 1 in which the lists were composed of only 10 items. If that was the case, we expected to find DF effect for the high span group and smaller or no DF effect for low span group.

## EXPERIMENT 3

### METHOD

**Participants**. The participants were undergraduate students from the University of Granada who received course credit for their participation. Thirty new participants were selected for participation in the low and high working memory span groups. These participants were identified by using the procedure described in Experiments 1 and 2. Fifteen participants were selected from the top third of the distribution of the reading-span scores (high span group) and fifteen from the bottom third (low span group). The averaged span values for the high and low span groups were 1.93 and 3.9, respectively. The difference between both groups was significant, $F$ (1, 28) = 161.4, $MS$ = 29.01, $p$ < .05.

**Design**. The design was identical to that described in Experiment 1.

**Procedure and Materials**. The procedure and materials were identical to those described in Experiment 1, except for the lists length. Sixty words of moderate to high frequency were drawn from Alameda & Cuetos (1995). For both the Remember and Forget tasks, two lists of fifteen words were presented. The lists were counterbalanced across tasks, and the words were randomly allocated to the lists in each task. Presentation rate and instructions were identical to those described in Experiment 1.

## RESULTS AND DISCUSSION

Average recall scores and standard deviations in each condition are presented in Table 3. Results from the Remember and Forget Condition are reported separately below.

**Table 3: Proportion of correct recall and standard deviations (in brackets) for each condition of Experiment 3.**

| | | Remember Task | Forget- Task |
|---|---|---|---|
| High Span | List 1 | .35 (.04) | .29 (.03) |
| | List 2 | .33 (.03) | .39 (.04) |
| Low Span | List 1 | .33 (.04) | .35 (.03) |
| | List 2 | .27 (.03) | .30 (.04) |

*Control-Remember Task.* A 2 (WM Span ) x 2 (List) analysis of variance (ANOVA) was performed on the proportion of recalled words in the Remember task. The main effects of WM Span and List were not significant, $F(1, 28) = 1.39$, $MS = .03$, $p>.05$ and $F(1, 28) = 1.77$, $MS = .03$, $p>.05$, respectively. In addition the interaction between WM Span and List was also non-significant, $F<1$. Thus, we found again that high and low span individuals showed similar patterns of recall when instructions to forget were not provided.

*DF-Forget Task.* The results of the 2 (WM Span) x 2 (List) ANOVA revealed no main effects of WM Span and List, *F*s<1, but the interaction WM Span x List was significant, $F\ (1, 28) = 4.64$, $MS = .09$, $p = .04$.

Planned comparisons of this interaction revealed that high span participants recalled significantly more words from List 2 than from List 1, $F\ (1, 28) = 4.36$, $MS = .08$, $p = .04$. In contrast, there was no difference between the proportion of words recalled from List 1 and List 2 for the low span group, $F<1$. As in Experiment 2, a DF effect was only observed in the high span group. Analyses of the cost and benefits for the high span group indicated that although the relevant comparisons did not reach significance, there was a tendency for the high span participants to recall fewer List 1 items in the forget than in the control condition ($p = .15$) and more List 2 items in the forget than in the control condition ($p = .10$). This suggests that the DF (List 1 recall < List 2 recall in the forget condition) was jointly produced by a small decrement in the recall of List 1 and a small increment in the recall of List 2 when forgetting instructions were provided.

As in Experiment 1 and 2, we performed a correlation between WM span and DF scores. Thus, for each participant in Experiment 3 we calculated a DF score by subtracting the proportion of recall for List 1 and List 2 in the forget condition. The results of this analysis showed a significant and positive correlation ($r = .50$, $p = .005$) between WM capacity and DF scores.

This pattern of results is similar to that found in Experiment 2. Again, increasing interference (now by varying list length) eliminated the DF effect for the low span group, but it produced a DF effect for the high span group. Thus, increasing interference by introducing longer lists of items produced differential effects on the high and low span groups. In this way, inhibition was triggered for the high span group, whereas there was not evidence of inhibition for the low span group. Probably, the increase in interference overloaded the cognitive resources of the low span group, so that they were not able to trigger inhibition.

## GENERAL DISCUSSION

People can intentionally forget previously learned information. Evidence for this type of intentional forgetting has been provided by using the list-method directed forgetting procedure. Several lines of research have suggested that the mechanism involved in directed forgetting is inhibitory in nature (Bjork, 1989; Bjork, Bjork & Anderson, 1998, but see Sahakyan & Delaney, 2005 for a non-inhibitory explanation). In addition, there is evidence supporting a strong relationship between WM capacity and the ability to inhibit irrelevant information (Conway et al., 2001; Kane et al., 2001; Long & Prat, 2002; Rosen & Engle, 1998; Soriano et al., 2004). In Experiment 1 to 3 we attempted to extend this relationship to the directed forgetting phenomenon by focusing on individual differences in WM and their relation to the DF effect. In addition, the introduction of a memory load in Experiment 2 and the increment of list length in Experiment 2 allowed us to explore the role of interference and availability of cognitive resources in producing the DF effect. We discuss first the role of WM capacity and interference in producing retrieval inhibition. Second we discuss the relation between the availability of cognitive resources and retrieval inhibition:

*WM capacity, interference and inhibition*.- Based on the results of previous studies showing greater inhibitory effects for people with high memory span than for people with low memory span, we expected that individuals with high WM capacity would show greater DF effects than individuals with low WM capacity. However, contrary to our predictions, in Experiment 1 we found reliable DF effects for the low span individuals and small unreliable DF effect for the high span participants. We explained this unexpected finding as due to differential susceptibility to interference for high and low span individual. It is possible that because of their memory capacity, the high span participants experienced relatively less interference than the low span participants, and therefore inhibition was not triggered for this group. A large body of research has shown that competition is a necessary condition for inhibition to occur (see Anderson, 2003 for a review). In fact within the directed forgetting literature, many experiments have shown that learning of the List 2 is necessary to produce DF effects (Bjork, 1989) and that DF effects disappear when the material can be integrated (Conway et al, 2000; Wilson, Kipp & Chapman, 2003). For example, Wilson et al. manipulated the semantic relation between the words in a DF task. They found that DF effects were not present when List 1 was composed of categorized words, indicating that when the material can be integrated during study, competition is reduced and inhibition is not triggered. Hence, competition needs to be present for inhibition to act. In this way, if the high span participants in Experiment 1 did not experience enough competition to trigger inhibition, it is not surprising that the DF effect was small and non-significant. So, we interpreted the absence of DF effect for high span participants in Experiment 1 as due to the lack of competition.

Note that this interpretation is based on the assumption that competition is not only dependent on the material to be learned but also on the cognitive resources of the learner. From this view, competition is not a stable property of the materials but a consequence of the interaction between the materials to be learned and the individuals that learn it. Consistent with this interpretation many studies have shown that low span individuals are more vulnerable to memory interference than high span individuals (Kane & Engle, 2000; Rosen & Engle, 1997).

Following this line of reasoning, increments in the amount of interference should produce DF effects for the high span individuals. We explored this hypothesis in Experiments 2 and 3 by introducing a memory load (Experiment 2) and by introducing longer lists (Experiment 3). Results from these experiments provided support for our hypothesis. Increasing competition in the learning material (both with a 6-digit memory load and with larger lists) produced reliable DF effects for the high span group. Hence, the results of Experiment 2 and 3 for the high span participants are consistent with previous results suggesting that competition is a necessary condition for inhibition to occur. Thus, for the high span participants DF effects were only evident when competition was increased by adding a memory load or by increasing list length.

However, some aspects of the data are intriguing and not completely consistent with this reasoning. We interpreted the lack of DF effect for the high span participants in Experiment 1 as due to the relatively small interference experienced by these subjects. If this was the case, we should have observed that in the control-remember condition, the high span group recalled more List 2 items than the low span participants. However, this was not the case, and the results indicated that both high and low span participants recalled the same proportion of List 2 items in the control condition. In addition, the presence of a working memory load or the increment of list length did not reduce the proportion of recall of List 2 in Experiments 2 and 3 relative to Experiment 1. Hence, although the results of our experiments provide further evidence for the important role of competition in producing DF effects, the relation between WM capacity, interference and direct forgetting is not completely clear and needs of further investigation.

Is this pattern of results better explained by other non-inhibitory accounts of directed forgetting? Recently, Sahakyan & Delaney (2005) have argued that the DF effect is produced by two separate components having different underlying mechanisms. Thus, the cost of DF would emerge from a context change mechanism, whereas the benefit of DF would emerge from better study strategies for List 2. According to this account, the presence of the forget cue induce participants to set a new mental context to encode the second list. Because of this new mental context, when participants are asked to recall items from the two lists there will be a mismatch between the List 1 context and the retrieval context that will lead to List 1 forgetting (cost of DF). On the other hand, when the forget cue is presented, participants are induced to evaluate their current encoding strategy and to adopt a better study strategy for List 2 (benefit of DF). Although this account has received some support (Sahakyan & Delaney, 2003, 2005; Sahakyan, Delaney & Kelley, 2004), it is not evident how it would explain the pattern of results in our experiments. For example, it can be argued that introducing a memory load before List 2 would increase the probability of setting a new mental context for List 2, and therefore the cost of DF would also increase. However, results from Experiment 2 suggest that the obtained DF effect was produced by the benefit of DF forgetting to a larger extent than by the cost of DF. Why should a memory load induce a better encoding strategy for List 2? In addition, it could also be argued that the absence of DF effect for high span participants in Experiment 1 can be due to their being less influenced by contextual changes than the low span participants in Experiment 1, but why introducing a memory load in Experiment 2 or increasing list length in Experiment 3 produced the opposite pattern of results? Hence, although some aspects of the data are puzzling from an interference-dependent inhibition account of DF, the overall pattern of results is better explained by it.

*Availability of cognitive resources and DF effects.-* Engle and colleagues (Engle, Kane & Tuholski, 1999) have proposed that WM capacity is related to the capability to use controlled attention to prevent interference. Individual differences in inhibition result from differences in controlled attentional resources. Thus, when individuals experience interference, inhibition is triggered, but if their cognitive resources are overloaded by the task demands, inhibition may not be possible. The pattern of results observed in Experiment 1 to 3 for the low span participants is consistent with this proposal. The presence of inhibition in the low span group depended on the amount of cognitive resources demanded by the task. Thus, when the task was relatively less demanding (Experiment 1), low span participants showed reliable DF effects. In contrast, when the task demands were increased by either including a memory load (Experiment 2) or by introducing larger numbers of words to remember (Experiment 3), the DF effect was abolished. We argued that these last results were caused by an overload of cognitive resources for the low span individual. A similar interpretation was provided by Wilson, Kipp & Daniels (2003) to their experiments on the role of task demands on retrieval inhibition in children. In their experiments DF effects were observed in 6-years-old children when the lists were categorized, but not when they were composed of unrelated words. However, DF effects with unrelated words were observed for 8 years-old children. They concluded that there are important developmental and individual differences in availability of cognitive resources and that inhibition depends on the availability of cognitive resources and on the task requirements. A task such as learning unrelated words may consume too many resources for 6-years children, so that very few are available for inhibition. Since the task is less consuming for 8 years-old children, inhibition is possible and DF effects are found. We suggest that these results are similar to those obtained in Experiment 2 and 3. Thus, when the task consumed too many resources for the low span group inhibition of List 1 was not observed. This is consistent with Engle et al.'s, (1995) proposal that individual differences in inhibition result from differences in controlled attentional resources. WM controlled resources (or Working attention) underlies inhibitory processes, as well as maintenance and other executive processes.

In summary, the overall pattern of results of Experiments 1 to 3 suggests that directed forgetting is produced by a single inhibitory mechanism that is dependent on both the presence of interference and the availability of controlled resources. In this sense, our data are consistent with the proposal by Anderson (2003; Levy & Anderson, 2002) that retrieval inhibition is similar to attentional inhibition. Both types of inhibition can be considered as executive processes that consume cognitive resources.

## RESUMEN

**Recursos de la Memoria de Trabajo e Interferencia en Olvido-Dirigido**. Investigaciones recientes han mostrado que la habilidad de inhibir información irrelevante está relacionada con la capacidad de la Memoria de Trabajo (MT). En tres experimentos, investigamos esta relación mediante la utilización de la tarea de olvido dirigido (OD) con el método de la lista en sujetos que diferían en su capacidad de MT. En contra de nuestras predicciones, en el Experimento 1 observamos el efecto de OD en los participantes de baja capacidad, mientras que los participantes de alta capacidad no mostraban este efecto. Estos resultados inesperados se interpretaron como causados por la diferente susceptibilidad a la interferencia de los sujetos de alta y baja capacidad. En los Experimentos 2 y 3, se aumentó el grado de interferencia mediante la introducción de una carga de memoria (Experimento 2) y mediante un aumento de la longitud de las listas (Experimento 3). Estas condiciones de más alta interferencia produjeron un cambio radical en el patrón de resultados, de manera que los sujetos de alta capacidad ahora mostraban el efecto de OD, mientras que los sujetos de baja capacidad no lo mostraban. El cambio en los efectos en los sujetos de alta y baja capacidad dependiente del grado de interferencia sugiere que la inhibición en la tarea de OD depende del grado de interferencia que experimentan los participantes y de la disponibilidad de recursos controlados.

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