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PREPRINT VERSION

Strategic adaptation to dual-task in verbal working memory: Potential routes for theory integration

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Abstract (235 words)

How Working Memory (WM) supports dual task performance is the focus of a longstanding debate. Most previous research on this topic has focused on participant performance data. In three experiments, we investigated whether changes in participant-reported strategies across single and dual task conditions might help resolve this debate by offering new insights that lead to fruitful integration of theories rather than perpetuating debate by attempting to identify which theory best fits the data. Results indicated that AS was associated with reduced reports of the use of Rehearsal and Clustering strategies but to an increase of the reported use of a Visual Strategy. Elaboration and Clustering strategies were reported less for memory under dual task compared with single task. Under both dual task and AS, more participants reported attempting to remember fewer memory items than were presented (Memory Reduction strategy). For arithmetic verification, AS and dual task resulted in a reduction in reports of a Counting strategy, and an increase in reports of a Retrieval strategy for arithmetic knowledge. It is argued that experimenters should not assume that participants perform the same task in the same way under different experimental conditions, and that careful investigation of how participants change their strategies in response to changes in experimental conditions has considerable potential for resolving theoretical challenges. It is argued further that this approach points towards the value of attempting to integrate rather than proliferate theories of WM.

Key Words: Working Memory; Strategies; Adaptation; Dual-Tasking; Articulatory Suppression

Working memory (WM) refers to a cognitive system that supports the storage and manipulation of information over periods of a few seconds, and is often assessed with tasks that include the memorization of information and a concurrent processing task. There is widespread agreement regarding the importance of WM in human cognition because it sustains high-level cognitive activities (for reviews see Baddeley, 2007; Conway, Jarrold, Kane, Miyake, & Towse, 2007; Logie, Camos, & Cowan, 2021a) as well as many moment-to-moment interactions with our environment. There is also a consensus that WM capacity is limited to a relatively small amount of information (e.g., Baddeley, 2012; Barrouillet & Camos, 2015; Cowan, 2010; Logie, 2011; Oberauer, 2002). However, despite this general agreement, several models of WM have been proposed that disagree as to how the combined memorization and processing of information can be achieved (e.g. Baddeley, 1986; 2012; Baddeley, Hitch, & Allen, 2018; Baddeley & Logie, 1999; Barrouillet, Bernadin, & Camos, 2004; Barrouillet & Camos, 2015, 2021; Cowan; 1999, 2005, 2015, 2016; Doherty et al., 2019; Logie, 2003; 2011; 2016; 2018; For recent reviews, see Logie et al., 2021a).

To address the debate regarding the interpretation of dual-tasking in WM, we combined the efforts of researchers associated with three different theoretical frameworks for WM, specifically the Time-Based Resource Sharing (TBRS) model by Barrouillet & Camos (2010; 2015; 2021), the Embedded Processes (EP) model by Cowan (1999; 2016; see also: Cowan, Morey & Naveh-Benjamin, 2021), and a version of the Multiple Component Model (MCM) (Baddeley & Logie, 1999; Logie, 1995; 2011; 2016; Logie, Belletier & Doherty, 2021), in a large project referred to as ‘WoMAAC’ for ‘Working memory across the adult lifespan: An adversarial collaboration’ (<https://womaac.psy.ed.ac.uk>; Cowan et al., 2020; Logie et al., 2021b). We are fully aware that there are other important theoretical frameworks for WM (for reviews see: Cowan, 2017; Logie, et al., 2021a). However, as discussed in detail below, the current paper focuses more on generally agreed principles of WM (for discussions see Cowan,

2017; Logie & Cowan, 2015; Logie et al., 2021b), and whether we can gain insight into how these principles operate (e.g. Doherty & al., 2019; Jaroslawska et al., 2020; Rhodes et al., 2019) from investigating how participants attempted to perform tasks under different conditions rather than testing differential predictions from any specific theories for patterns of performance among participants. In doing so, we aim to gain new insights into WM functions that are not clear from performance data patterns alone, and that may place constraints on and provide leads to future development of WM theory.

Although the use of different strategies in cognitive tasks has been considered previously in a range of domains (e.g. Fazio, Dewolf, & Siegler, 2016; Logie, Della Sala, Laiacona, Chalmers & Wynn, 1996; Morrison, Rosenbaum, Fair, & Chein, 2016; Siegler, 1987), the rationale for exploring the importance of strategies in working memory tasks was articulated recently by Logie (2018) as follows: "...for many cognitive tasks, there might be more than one way to achieve a high or a low level of performance. The same level of performance might be achieved in different ways, or using different strategies" (p.2). For example, when facing a difficult cognitive task, individuals tend to use strategies in a way that maximizes task performance (e.g., Fazio et al., 2016). Most studies that investigate the impact of dual-task demands in performance on a memory task and a processing task when they are performed together compared with being performed separately, (i.e., dual-task costs) consider only the possibility of concurrent use by both tasks of a cognitive function that is common between them. Rarely do such studies consider changes in which cognitive functions are used and how those functions are employed in dual-task situations in attempts to limit the performance cost.

Our aim in this article was therefore to analyze strategies in dual tasks situations. For this purpose, we used data on strategies reported by participants in Doherty et al. (2019) that have so far been neither exploited nor published, as well as new data including a trial-by-trial

assessment of the reported strategies. In so doing, we hoped to shed additional light on the observed performance data, and consider whether this might lead to new theoretical developments. More generally, focusing on strategies might bring a new perspective on dual-tasking in WM. First, we present a brief review of key previous studies on dual tasking in working memory, and an overview of the three theoretical frameworks that led to the original design of the experiments. Then we discuss previous research on strategy use in working memory tasks, before turning to the background for the current study and presentation of our results from the analyses of reported strategies of two already published experiments (Doherty et al., 2019) and of an additional experiment.

Dual-tasking in Working Memory

A major challenge for understanding human cognition is to explain how human beings manage dual-tasking or, more specifically, how WM, the cognitive system thought to support both temporary memory and processing, can jointly achieve these two activities. The current literature provides two distinct accounts for this issue. We have already stated above that our focus is on MCM, EP, and TBRS conceptual models of WM, reflecting the theoretical frameworks associated with the three teams of researchers involved in these studies. On the one hand, models like MCM assume that separate resources can be devoted respectively to storage or processing, and that these separate resources can function in parallel, but that they can work together to support overall dual task performance (e.g. Baddeley, 1986; Baddeley & Hitch, 1974; Baddeley & Logie, 1999; Logie, 2011). On the other hand, early versions of the EP model and the TBRS model assumed that a general resource has to be shared between the two activities (Barrouillet, et al., 2004; Saults & Cowan, 2007). However, more recent versions of these theories contain other components that are not assumed to conflict with concurrent processing (e.g. rehearsal, and offloading information to activated LTM) (e.g. Barrouillet & Camos, 2015;

Camos, 2017; Cowan, Sauls, & Blume, 2014) or are assumed to conflict very little with it (Cowan, 1988, 1999, 2016). There is currently insufficient evidence to settle the debate between these theoretical views, because substantial evidence has been gathered to support each of them. One possible reason why the debate has had such longevity, and why several other theoretical perspectives on WM have been proposed (for reviews see Cowan, 2017; Logie et al., 2021a), could be that competition between theories results in a given theory seeming superior in accounting for one data set, whereas some other theory appears to provide the best account for a different data set. This could serve simply to perpetuate debate indefinitely without necessarily leading to substantial new insights into human cognition (Logie et al., 2021b). An alternative is to consider the commonalities between theories, and explore whether attempting to integrate rather than compete for theoretical dominance might yield those new substantial insights, and be more fruitful for theoretical development. Therefore, one possible resolution for the debate could be that all three types of theory are at least partially correct, but that they each may embody different strategies for performing particular experimental tasks. Our approach to attempting that resolution was for different labs to adopt the same experimental methods, protocols, and materials, and hence avoid the potential for specific methods to generate data patterns that are consistent with the assumptions only of a specific theoretical position.

The absence of a dual-task cost (or minimal cost) when processing is performed while holding information in memory has been considered as major evidence to support the existence of distinct resources sustaining the different activities (Baddeley & Hitch, 1974; Doherty & Logie, 2016; Logie, Cocchini, Della Sala, & Baddeley, 2004). Doherty and Logie (2016) investigated the reciprocal effects of a verbal memory task (i.e., maintaining a series of digits) while performing a spatial task (i.e., judging the location of a square above or below the center of the screen) by manipulating the load induced by each task around the individual span level

for each task for each participant. They found that increasing the spatial processing load had no effect on memory performance and that memory load did not affect performance in the processing task when performed at individual span level. Only when memory load exceeded the individual span level was a reduced accuracy in the spatial task observed. The authors' interpretation was that memory and processing demands can be handled by independent resources, as suggested earlier by Logie et al., 2004. However, when demands exceed capacity of a given resource, additional resources were assumed to have been engaged, resulting in an impairment of the concurrent processing.

Seeming to contradict the evidence of Doherty and Logie (2016), other studies have shown more continuous tradeoffs between storage and processing as the demands of the two tasks are manipulated, with increases in memory load slowing processing and with increased speed of processing reducing the available resources for memory (Barrouillet et al., 2004; Barrouillet, Bernardin, Portrat, Vergauwe, & Camos, 2007; Barrouillet, Portrat & Camos, 2011; Camos, Johnson, Loaiza, Portrat, Souza & Vergauwe, 2018; Chen & Cowan, 2009; Vergauwe, Barrouillet, & Camos, 2010). However, it is notable that those studies have tended not to adjust task demands to the span of each individual participant, although most of these studies used span procedures, avoiding memory overload. Moreover, in the original Baddeley and Hitch (1974) experiments, memory loads of six items resulted in slowing of reasoning and language processing whereas memory loads of three items did not. Consistent with the Baddeley and Hitch (1974) finding, Chen and Cowan (2009), showed that a speeded choice reaction time task with simple visual-spatial stimuli was increasingly impaired by an increasing verbal memory load (digits) when the memory list exceeded three items. Similarly, Vergauwe, Camos and Barrouillet (2014) systematically increased the number of memory items to be retained, and reported a linear increase in the response times on spatial fit, color discrimination, and parity judgment tasks (see also Camos, Mora, Oftinger, Mariz & Schneider, 2018a). This effect is

analogous to the cognitive load effect in which the increase in concurrent assumed attentional demand results in a linear decrease in recall performance (see for reviews, Barrouillet & Camos, 2010, 2012, 2015, 2021).

To address these apparently contradictory findings, and to gather evidence that might help resolve the debate, the WoMAAC group designed a series of experiments comparing performance in single- vs. dual-task situations. Young adults performed serial recall of aurally and visually presented letters, and a simple addition verification task either alone (single-task) or in combination (dual-task) with the verification task performed between presentation and recall of letter sequences (Doherty et al., 2019). Both tasks were presented at individual span level of approximately 80% correct performance when performed alone.

The findings on participant performance (memory and processing errors) did not closely fit any of the three contrasting theoretical views. Specifically, while memory performance suffered from a dual-task cost as expected by the resource-sharing hypothesis, processing was at most only minimally affected by the concurrent maintenance of information, as expected by the MCM hypothesis. Although these results do not allow a simple decision between theories, they show that each theoretical view may have merit that could lead to theoretical integration. This could offer genuine advance in understanding rather than the more common approach of aiming to show that one theory is correct and others are not. A systematic investigation of possible use of strategies could indicate a path towards that integration.

Memory Strategies in Working Memory

A first and important distinction between strategies in WM contrasts the verbal (e.g., letters, words, numbers) vs visual (e.g., pattern of dots, shapes, colors) nature of the memoranda that participants have to memorize. Here, we will focus on strategies in verbal WM that have been more intensively studied and are relevant for the experiments we report (for research on

visual WM, see for example Atkinson, Baddeley & Allen, 2017; Bengson & Luck, 2016; Bor, Duncan, Wiseman & Owen, 2003; Brown, Forbes & McConnell, 2006; Cusack, Lehman, Veldsman, Mitchell, 2009; Linke, Vicente-Grabovetsky, Mitchell & Cusack, 2011; Logie, Saito, Morita, Varma & Norris, 2016; Shimi & Logie, 2019; for a review of early work see Logie, 1995).

Because one may expect that individuals try to maximize task performance in using strategies (e.g., Fazio et al., 2016), these strategies may vary from one individual to another, but also for the same individual on the same task presented on two separate occasions or in different trials during the same session (Logie et al., 1996; Siegler 1987; 1995; for a recent review and discussion see Logie, 2018). The flow of information in WM has long been assumed to be at least in part under the immediate control of individuals (Atkinson & Shiffrin, 1971; Broadbent, 1958; James, 1890). Hence, different strategies should sustain WM maintenance depending on the characteristics of the task or the individual. At first glance, it may seem that numerous strategies would then be identified and studied in the field of WM. However, a closer look at this research indicates that these numerous strategies can be regrouped into a small number of categories.

The most frequently reported strategy to maintain verbal information in WM is phonological rehearsal, or simply *Rehearsal*, for which participants repeat the memoranda out loud or sub-vocally (e.g., Bailey Dunlosky & Hertzog, 2009; Dunlosky & Kane, 2007; Friedman & Miyake, 2004; Logie et al., 1996; Miller, McCulloch & Jarrold, 2015; Morrison et al., 2016; Turley-Ames & Whitfield, 2003; Unsworth, 2016). Besides Rehearsal, four other main strategies have been described in verbal WM. *Temporal Clustering* refers to the grouping in clusters of 2 or 3 items, without any reference to prior knowledge, for example grouping XQBPWM into XQB and PWM. This is likely to rely to some extent on rehearsal of the groups and items within groups (Bor & Owen, 2007; Harris & De Qualls, 2000; Hitch, Burgess, Towse

& Culpin, 1996; Logie et al., 1996; Swanson, Kehler & Jerman 2010). On the contrary, *Chaining* or *Elaboration* both refer to the formation of links between the memoranda using some prior knowledge (Bor & Owen, 2007; Harris & De Qualls, 2000; Kaakinen & Hyönä, 2007; McNamara & Scott, 2001; Swanson et al., 2010). This can be achieved, for example, by creating some semantic associations (Friedman & Miyake, 2004; Harris & De Qualls, 2000; Logie et al., 1996; Swanson et al., 2010), or a sentence (Bailey et al., 2009; Bailey, Dunlosky & Kane, 2008; Cokely, Kelley & Gilchrist, 2006; Dunlosky & Kane, 2007; McNamara & Scott, 2001; St Clair-Thompson, Stevens, Hunt & Bolder, 2010; Turley-Ames & Whitfield, 2003; Unsworth, 2016; Unsworth & Spillers, 2010a). *Visual Imagery* can refer to the creation of a mental image based on the item meaning (e.g. Borst, Niven & Logie, 2012; Carretti, Borella & De Beni, 2007; Miller et al., 2015; Morrison et al., 2016; Paivio, 1971), but could also refer to retention of the visual appearance of the shape of the letters and words (Logie Della Sala, Wynn, & Baddeley, 2000; Logie et al., 2016; Saito, Logie, Morita, & Law, 2008). Finally, a *Memory Reduction* strategy, in which participants try to remember only a subset of the presented items in a given trial, has been shown to be helpful in the case of visual working memory (e.g., Cusack et al., 2009). Similarly, participants in a verbal working memory task might use a form of memory reduction to manage their performance under dual task conditions.

It should be noted that strategies from different categories can be used in combination to maintain the same series of items. For example, Temporal Clustering and Elaboration may be combined when individuals use a group of two or three memoranda following each other to make a link with previous knowledge (for example, the string of letters WMCTDK may be first clustered WMC-TDK, and then WMC can be elaborated as Working Memory Capacity).

The use of strategies can modulate memory performance, and the link between strategies and performance has been mostly discussed in the context of studies that compare high- to low-WMC individuals. Engle, Cantor, and Carullo (1992) were among the first to address this

question by measuring the time spent on different parts of two self-paced WM tasks (an operation and a reading span task), these times being conceived as indirect indicators of the use of strategies. Their results showed that individuals spent more time processing the to-be-remembered words as the memory load increased, this effect being stronger in high-WMC individuals. More recently, Kaakinen and Hyönä (2007) also examined the time spent on the different elements of a reading span task, but also recorded eye movements and fixations. In line with Engle et al.'s (1992) findings, they found that participants spent more time gazing at the to-be-remembered words when memory load increased, but they did not observe any difference as a function of participants' WMC. In a second experiment, asking participants to report their strategies, they showed that high-WMC participants reported using more frequently Chaining or Imagery than low-WMC individuals. Together, these results led the authors to conclude that individual differences in performing a reading span task do not depend on the allocation of the time to the different elements of the task, but on the capacity to use more effective strategies.

McNamara and Scott (2001) found that training to use the Chaining strategy significantly improved WM performance in comparison with a control group that completed training trials without specific instructions. McNamara and Scott (2001) also noted that even the less-strategic individuals were able to benefit from this training, which is consistent with their strategy mediation hypothesis, according to which performance depends mainly on the strategies used by participants. Turley-Ames and Whitfield (2003) showed that training to use Rehearsal was beneficial only for low-WMC participants. Moreover, Dunlosky and Kane (2007) showed that in an operation span task, trial-by-trial reports of strategies correlated with recall performance in that effective strategies were associated with better recall than ineffective strategies (see also, Bailey et al., 2008, 2009; Harris & De Qualls, 2000). Note that, in these studies, Elaboration, Chaining or Imagery were considered as effective strategies to maintain

verbal information in WM. Rehearsal was considered an ineffective strategy, because the latter typically leads to poorer performance than the former in complex span tasks in which the concurrent task (reading sentences or operations) is performed aloud (e.g., Bailey et al., 2009; Bailey et al., 2008; Dunlosky & Kane, 2007; Harris & Qualls, 2000; McNamara & Scott, 2001). In line with Dunlosky and Kane (2007), Cokely et al. (2006) observed that the differences in recall performance between high- and low-WMC individuals disappeared after training to use the Chaining strategy, consistent with the idea that the superiority in recall performance of the high-WMC individuals is due to the use of effective strategies

To sum up, recall performance depends at least in part on the type of strategies that individuals employ. However, none of these studies examined whether participants adapt their strategy to task constraints. Nonetheless, some findings can give some hints about strategic adaptations. We noted before that Rehearsal was considered as an ineffective strategy in tasks that require some overt verbal production concurrent with the maintenance of verbal items. Other strategies that are not based on the speech production system such as Visual Strategies and Elaboration, or that supplement Rehearsal with Temporal Clustering have been shown to be effective. Hence, investigating strategies and how they change across WM tasks and experimental conditions should help understanding of the type of cognitive resources that support dual-tasking in WM.

The Present Study

In the present study, participants performed a memory task with memoranda presented either visually (Exp. 1 and 3) or aurally (Exp. 2), and a visually presented simple arithmetic verification task. These tasks were performed in isolation, then jointly with the arithmetic performed during a ten second retention interval between presentation of the memoranda and serial ordered recall, and then again in isolation. With visual presentation, participants recalled

the memoranda by typing on the keyboard. With aural presentation, recall was oral. Moreover, tasks were performed with and without AS.

Given the evidence that individuals can adapt their strategies according to the task at hand (Logie et al., 1996; Morrison et al, 2016), we might expect that, when facing an increased cognitive demand in a dual-task compared to the single task condition, individuals should rely less on cognitively demanding strategies, and more on low-demanding strategies. Nonetheless, one could expect that participants should adapt their strategies not only to memorize items and retain them in memory, but also to perform the concurrent processing task.

The introduction of AS that has been known for some time to disrupt rehearsal (e.g. Baddeley, Lewis, & Vallar 1984; Murray, 1965) should lead participants to reduce the use of Rehearsal and Temporal Clustering, but have no effect on, or possibly increase the use of, Elaboration and Visual strategies. Supporting the notion of rehearsal as consuming few general resources, Naveh-Benjamin and Jonides (1984) showed an effect on performance only for the first few iterations of rehearsal. Therefore, a dual task in our paradigm, should have little or no impact on the use of Rehearsal, but should affect the use of Elaboration and Visual strategies (see Thalmann, Souza, & Oberauer, 2019 for an alternative view).

Note that almost all the studies cited in the previous section only assessed the effects of strategies on memory. Although the vast majority of these studies used paradigms involving a concurrent processing task, possible strategy changes in the processing task have rarely been explored. Only a few studies have examined the effects of strategies on the concurrent task, but only by assessing the time spent on it by participants, which is only an indirect measure of strategies (Brébion, Smith & Ehrlich, 1997; Engle, et al, 1992; Kaakinen & Hyönä, 2007).

The concurrent processing in Experiments 1, 2 and 3 of a simple arithmetic verification task (e.g. $6+7=14$ True or False?), has been shown in previous studies to be achieved through two main strategies (DeStefano & Lefevre, 2004; Hecht, 2002; LeFevre, Sadesky & Bisanz,

1996). The first, Counting, refers to the algorithmic computing of the sum, and then its comparison with the displayed answer. The computation can be achieved either through “min counting” (i.e. counting from the larger addend the number of increments corresponding to the smaller addend; Hecht, 2002) or “decomposition” (i.e. using a known addition and then completing by counting, such as solving $6+7$ by first retrieving the result of $6+6$, and then add 1; Hecht, 2002). The second strategy, Retrieval, does not involve computation, but relies on automatic processes, either the retrieval of the answer from long-term memory (Hecht, 2002) or a plausibility judgment (i.e., the equation just looks correct or incorrect; De Rammelaere, Stuyven & Vandierendonck, 2001; Lemaire & Fayol, 1995). Contrary to Retrieval, Counting requires keeping track of a running total and retention in memory of the addends and the proposed solution (Butterworth, Cipolotti & Warrington, 1996; Camos & Barrouillet, 2004; Craik, Govoni, Naveh-Benjamin & Anderson, 1996; De Rammelaere, Stuyven & Vandierendonck, 1999; Hecht, 2002; Lemaire, Abdi & Fayol, 1996; Logie & Baddeley, 1987). Therefore, we predict that an increase in cognitive demand from a concurrent memory load would lead participants to favor the least demanding strategy, namely Retrieval, so a dual task should not disrupt the use of this strategy. Because of the use of subvocalisation during a counting but not a retrieval strategy, AS should disrupt the use of counting, but not the use of retrieval.

In the current study, our aim was thus to investigate four questions: 1) whether dual task would reduce the number of strategies reported, or would show a more specific effect on the reports of Elaboration and Visual strategies in memory, but not on reports of Rehearsal; 2) whether AS would reduce the number of strategies reported or have a specific effect on the reports of Rehearsal and Temporal Grouping, 3) whether dual task and AS together will show an additive or interactive effect on the reports of strategies, and 4) whether these adaptations would occur for the memory strategies only, and so would mimic the observed results in

performance (only memory performance was affected by dual-tasking in the analyses done by Doherty et al, 2019), or whether strategy adaptations would occur for both processing and memory strategies.

As noted above, Doherty et al. (2019) reported that, concerning the performance data of Experiments 1 and 2 in the current manuscript, memory performance was affected by dual-tasking, but there was little or no impact of dual task on arithmetic verification. Studying strategy changes could reveal the source of this asymmetric effect. For example, if participants chose to give priority to the performance of the concurrent processing, their performance in the arithmetic verification task would remain relatively unaffected, but at the cost of a degraded recall performance (Belletier, Camos & Barrouillet, 2020). An additional possibility is that processing performance might be maintained under AS or dual task because participants switch to relying more on a retrieval strategy and this compensates for the reduction in the use of a counting strategy to help maintain performance levels.

Experiment 1

First, we summarize the methodology and main findings on participants' performance from Doherty et al. (2019) Experiment 1. This sets the context for our analyses in the current manuscript of reported strategies from that experiment. Full details are reported in the previously published manuscript. Our methods, along with the predictions and analysis plan for the performance data were preregistered on the Open Science Framework (<https://bit.ly/2KTKMgb>). Strategy reports were the focus of additional exploratory analyses after the experiments were completed when it became clear that theoretical closure could not be achieved from considering the performance data alone.

Method

Participants. Participants were 64 undergraduate students (age: $M=22.19$; $SD=2.97$),

half of them being from University of Edinburgh, UK., who completed the tasks in English, with an experimenter (JD) whose native language was English and half of them from Fribourg and Geneva Universities, Switzerland, who completed the tasks in French with an experimenter (CB) whose native language was French. The split of data collection across different labs, different languages, and different experimenters allowed for parallel replication of the experiment to ensure that our results were robust and generalized beyond a single lab. Participants received financial compensation (£12) in the United Kingdom, and course credit or a cinema voucher in Switzerland. Participants all had normal or corrected-to-normal vision, and were naive concerning the purpose of the experiment, which was presented as a study on memory. This experiment, and all subsequent experiments, were approved by the ethics committees for The University of Edinburgh, The University of Fribourg, and The University of Geneva. Experiment 3 was also approved by the ethic committee of University of Clermont Auvergne (IRB-UCA).

Material and Procedure. The task was run using PsychoPy (Peirce, 2007), and the experimenter remained in the experimental room during the experiment. All participants first performed a recognition task to check if the letters used as memory items were distinguishable from each other (all the consonants were used, except W, Y, and Z). The distance between the participants and the screen was around 60 cm, and each visually presented stimulus subtended approximately 1.3 degrees. Participants then completed two titration procedures for assessing the span levels (set at 80% accuracy) for memory and for processing for each individual. The order of the two was counterbalanced across participants. They then performed the experiment, including 10 trials of the memory single task and 10 trials of the processing single task at their span level. These were followed by 20 trials of the dual-task, combining memory for the letter sequences with the addition verifications during a ten second retention interval. Finally, participants performed again 10 trials of the two single tasks. The entire experimental procedure

was carried out twice, respectively with and without AS, the order of the two (without/with AS), and of the single tasks (memory and processing) being counterbalanced. The first single tasks (memory and processing) with AS and the two-dual tasks (with and without AS) included 3 trials of practice (the whole procedure is summarized in Figure 1). At the end of the experiment, the participants completed an open-ended questionnaire about their strategies. We chose to ask participants about their strategies after they had completed all of the experimental conditions to ensure that their report of strategies did not prompt strategy changes that would not have happened spontaneously.

Titration Procedure. A staircase procedure was implemented to evaluate the individual span level of each participant for both the memory and the processing task. In the memory task, 5 letters were presented sequentially in the center of screen for 250ms each, with an inter-stimulus-interval (ISI) of 750ms in the first pairs of trials. Participants had to remember the letters for a duration of 10 seconds during which a blinking circle was displayed in the center of the screen. Participants were then asked to recall the letters in their order of presentation by using the keyboard. If their average performance for this pair of trials was greater than or equal to 80%, the pair included one additional stimulus, in this case 6 letters, otherwise one less item was presented, in this case 4 letters. This procedure was repeated for 8 pairs of trials. If the last pair was the best score achieved (the highest number of letters remembered), additional pairs of trials were presented until the participants failed to achieve the 80% criterion. The memory span was defined as the highest number of letters remembered at 80% performance. Three training trials with 4 letters were presented at the beginning of the task.

The titration procedure for processing was similar. In the first pair of trials, participants saw five placeholders (diamond shapes) that appeared for 250ms with a 750ms ISI and then performed five addition verifications ($7+4=12$?) in 10 seconds by pressing the left (or right) key of a response box if the addition was incorrect (or correct). If the 80% criterion was

achieved on this pair, participants would have to perform one supplementary addition verification in 10s, and one less if the criterion was not achieved. Additions were constructed by picking at random two numbers between 1 and 9, the displayed results of each addition being either correct or incorrect (50 % each). The incorrect results differed by 1 above or below the correct response.

Single Tasks. In the memory single-task, a number of letters equal to the individual span of the participant was presented sequentially in the center of screen. Each letter appeared for 250ms, with an inter-stimulus-interval (ISI) of 750ms. As in the titration procedure, participants had to remember the letters for a duration of 10 seconds during which a blinking circle was displayed in the center of the screen. Participants were then asked to recall the letters in their order of presentation by using the keyboard. In the processing single-task, participants first saw five placeholders as in the titration procedure, and then had to verify during 10 seconds a number of addition equal to their individual span. It should be noted that half of the trials of the two single tasks were carried out before the dual-task, while the other half were carried out afterwards. Fatigue or learning effects were therefore controlled by combining the data from these two halves. The two single tasks were done once without and once with AS. In the latter case, participants had to repeat “ba-ba-ba” from the beginning of the trial (before the letters or the placeholders were displayed) and until the recall, at a rate of one syllable per second. Two tones indicated to the participants when to begin and when to stop the concurrent articulation.

Dual Task. The procedure for the dual-task condition combined the two single tasks. Participants first saw a number of letters equal to their individual memory span that were visually displayed on the screen (as during the single task). They then had to judge for 10 seconds a number of additions equal to their individual processing span. They then recalled as many letters as possible by typing them on the keyboard. Participants were asked to do their best on the two components (“Remember the letters in the order that you heard them, and at the

same time decide as quickly and accurately as possible whether each equation is correct or not”).

Figure 1 about here

Strategy Questionnaire. The questionnaire included 8 open-ended questions. The first four questions were about the memory strategies used by the participants in each of the 4 experimental conditions: single and dual task without and with AS. The last four questions of the questionnaire were about the strategies to verify the additions, and followed the same rationale as the questions about the memory strategies (see Table 1 for the exact wording of all questions).

Table 1 about here

Results

Performance. As noted earlier, the present paper focuses on strategic adaptation and the results concerning performance (but not strategies) in the memory and arithmetic tasks are reported in detail in Doherty et al. (2019). In summary, the titration procedure revealed a mean span of 6.30 (SD=1.30) on the letter memory task and of 8.00 (SD=2.0) on the addition verification task. Participants recalled fewer letters in the dual-task than in the single-task condition (scaled effect size: -0.73). The main effect of concurrent articulation was also significant, with fewer letters recalled under concurrent articulation than without concurrent articulation (scaled effect size: -2.96). Performance on the processing task was not affected by either the task condition or by the concurrent articulation. We also explored the presence of possible fatigue effects by comparing the first and second blocks of simple tasks. The results (see Supp Text S1) were in favor of the absence of such effects.

Memory strategies. Fifteen participants were excluded from analyses on the strategies because they did not report any strategy or did not complete the questionnaire. Some of these participants misunderstood the questions and instead reported how they felt about the task. The

analyses on the reported strategies were therefore based on 49 participants (20 from the UK, and 29 from Switzerland).

Classification of memory strategies. As mentioned in the Introduction, four main memory strategies have been described in the literature (Table 2). These strategies were also reported by our participants and we classified participants' answers to the questionnaire in accordance with the following definition of these strategies, consistent with previous literature identified in the Introduction¹. When participants reported repetition of the letters (aloud or subvocally), the strategy was classified as Rehearsal. When they reported grouping the letters, the strategy was classified as Temporal Clustering. When they reported associating letters with previous knowledge such as words (e.g., forenames) or acronyms, the strategy was classified as Elaboration. When participants reported visualizing the letters (sometimes by looking at the keyboard), it was classified as a Visual Strategy. Besides these four strategies, and based on our participants' responses, we added three other categories of strategies. Some of our participants reported having focused on the sound of the voice, and we thus classified this as an Acoustic strategy. Note that such a strategy has been already observed by Morrison et al. (2016). Some also reported reduction of memory load by attempting to remember only a subset of the letters presented, and/or they reported focusing on the arithmetic verification task. We named this the Memory Reduction strategy. Finally, miscellaneous strategies were labeled as other strategies.

¹ The classification of the strategies was submitted to an inter-judge procedure. In a first step, two judges independently classified participants' responses. In a second step, the way the strategy classes were understood was compared for the responses in which a discrepancy was observed. Finally, in a third step, the judges completed a new independent classification of participants' responses from which a correlation was calculated. This procedure was completed for all the English-speaking participants and for 15% of the French-speaking participants selected randomly. In Experiment 1, the correlation was .84 for the English-speaking participants and .94 for the French speaking-participants. In Experiment 2, the correlation was .86 for the English-speaking participants and .95 for the French speaking-participants. For remaining discrepancies, the judges agreed on which classification should be used for analyses. It is to be noted that we have chosen to process only 15% of the French-speaking participants for practical reasons, specifically difficulty in recruiting independent judges in Switzerland who were willing to spend the additional time required for checking all of the data for French-speaking participants. Nevertheless, the fact that Experiments 1 and 2 show similar results suggests that this did not impact the results. Even more convincingly, in Experiment 3, we used a trial-by-trial report of strategies in response to specific questions rather than open-ended reports at the end of the experiment, so there was no need for inter-judge ratings of reports, and yet the results are very similar to those from Experiments 1 and 2.

For each strategy and for each question, each participant's response was coded 1 when s/he reported to have used a given strategy and 0 otherwise, allowing the use of several strategies for each condition.

Table 2 about here

Number of strategies. Most of the strategies involved participants trying to maximize the number of items recalled from the set presented. However, the Memory Reduction strategy involved participants attempting to remember only a subset of those items, and therefore is a different kind of strategy that reduces the overall memory load. So, we might expect that as the demands on cognition increase, then the incidence of Memory Reduction also should increase. In contrast, we might expect other strategies to be reduced when the cognitive demands increase. Therefore, we did not include the Memory Reduction strategy in the analysis for investigating whether the number of reported strategies decreased when AS or dual task (or both) were introduced. It was analyzed separately when investigating the effect of each condition on each strategy type.

The number of different strategies reported across all conditions ($M=1.03$; $SE=.06$) was computed for each participant in each condition and analyzed using a repeated measures ANOVA with AS (with vs. without) and Task (single vs. dual) as within-subject factors. Notably, some participants reported no strategies, or only reported Memory Reduction, so some means are less than 1.0. The main effect of the Task was significant $F(1,48)=12.39$; $p<.001$; $\eta_p^2=.21$. Participants reported more strategies in the single Task ($M=1.17$; $SE=.07$) than in the dual Task ($M=.89$; $SE=.08$). The main effect of AS was also significant $F(1,48)=10.31$; $p<.01$; $\eta_p^2=.18$, with more strategies reported without AS ($M=1.16$; $SE=.07$) than with AS ($M=.90$; $SE=.08$). The interaction between the Task and AS was not significant ($p=.24$).

In the single task without AS all the participants reported at least one strategy. No participants reported using only the Memory Reduction strategy. In the dual task without AS

two participants reported no strategies, and six reported that they only used the Memory Reduction strategy. In the single task with AS, six participants reported no strategies, and three reported using only the Memory Reduction Strategy. Finally, in the dual task with AS condition five participants reported no strategies, and 13 participants only reported the Memory Reduction strategy.

Strategy use. Generalized Estimating Equations (GEE) were performed for each strategy (including Memory Reduction) across conditions as within-participant factors, specifically AS (with vs. without) and Task (single vs. dual). Data with dichotomous variables do not conform to the assumptions of ANOVAs, because performance is constrained between 0 and 1. This can lead to unequal variance between conditions, and possibly confidence intervals with limits larger than 1 or smaller than 0. In the case of repeated-measures designs, one possibility to address these issues is to use GEE (Ballinger, 2004; Wang, 2014). The factorial model (including the interaction between the two variables) was systematically tested first. If the interaction was not significant, the additive model (the model without the interaction) was tested and reported (see Figure 2 for an overview of the results). In the following results sections, odds ratios (OR) are reported and provide an account for the change between the two modalities, as predicted by the model. For example, an OR of .5 indicates a reduction by two between the two modalities. Similarly, an OR of 1 indicates no change between the two modalities, and a confidence interval (CI) including 1 indicates a non-significant effect.

The results are illustrated in Figure 2, and details of the analyses are reported in Table 3. These results indicated that dual-task led to more reports of the use of the Memory Reduction strategy than in the single-task ($OR = 9.42$; $CI\ 95\% = 4.23, 20.95$), accompanied by fewer reports of the use of Elaboration ($OR = .53$; $CI\ 95\% = .30, .94$), and Temporal Clustering ($OR = .48$; $CI\ 95\% = .30, .78$). AS led to more reports of the use of Visual Strategy ($OR = 3.29$; $CI\ 95\% = 1.36,$

7.98) and Memory Reduction strategy ($OR = 3.07$; $CI\ 95\% = 1.39, 6.81$), but less report of the use of Rehearsal ($OR = .28$; $CI\ 95\% = .15, .51$) and Temporal Clustering ($OR = .55$; $CI\ 95\% = .32, .95$). No significant interactions between the task conditions and AS were found for any of the memory strategies.

Figure 2 and Table 3 about here

Processing Strategies. We expected that the arithmetic verification task was solved either by Counting, that is through a step-by-step computation, or by Retrieval of well-learned mathematical ‘facts’ or a sense of familiarity (or “intuition”) about whether or not the equations looked as if they were correct (Table 4). In addition to these strategies, some of our participants reported that they ignored some or all of the addition problems to focus on the memory task. This was the equivalent behavior of what we observed for the memory strategies. We classified this as a Processing Reduction strategy. Finally, miscellaneous strategies that did not unambiguously fall within our strategy categories were labeled as other strategies. As for the memory strategies, each participant’s response was coded 1 when s/he reported having used a given strategy and 0 otherwise, allowing several strategies by condition.

Table 4 about here

Number of strategies. As for memory strategies, and for the same reasons, we did not include Processing Reduction in this analysis. The number of different strategies reported ($M = 1.07$; $SE = .07$) was computed for each participant in each condition. The same analyses were used as for the memory strategies. Notably, some participants reported no strategies, or only reported Processing Reduction, so some means are less than 1.0. The main effect of the Task was significant $F(1,48) = 9.82$; $p < .01$; $\eta_p^2 = .17$. Participants reported more strategies in the single task ($M = 1.17$; $SE = .07$) than in the dual task ($M = .96$; $SE = .08$). Neither the main effect of AS nor the interaction between the two factors were significant, $ps > .32$.

In the single task without AS, four participants reported zero strategies, and none of the participants reported only Processing Reduction. Six participants did not report at least one strategy, and 2 reported only the Processing Reduction in the dual task without AS. In the single task with AS, 3 participants did not report at least one strategy, and none of the participants reported only Processing Reduction. Finally, in the dual task with AS, 8 participants did not report at least one strategy, and 2 reported only the Processing Reduction Strategy.

Strategy use. The same analyses were performed as for the memory strategies (including Processing Reduction). Results are illustrated in Figure 3, and details of the analyses are shown in Table 5. For Counting, a factorial model was preferred, because the main effects of Task, the main effect of AS and their interaction were significant. In single-task conditions, Counting was less often reported under AS ($OR = .33$; $CI\ 95\% = .19, .56$). However, in the dual-task conditions, no difference emerged in reporting Counting in the conditions with or without AS ($OR = .83$; $CI\ 95\% = .59, 1.19$). A factorial model was also preferred for Retrieval, because the Task x AS interaction was significant. The main effect of AS was also significant. In the single-task conditions, Retrieval was more often reported under AS ($OR = 1.96$; with $CI\ 95\% = 1.20, 3.22$). In the dual-task conditions, reports of Retrieval did not differ between the conditions with or without AS ($OR = 1.00$; $CI\ 95\% = .72, 1.39$).

Figure 3 and Table 5 about here

Discussion

Our main aim was to examine changes in strategies in both memory and processing to gain new insights into the effects of dual-tasking and articulatory suppression (AS) reported for performance data in Doherty et al. (2019) Experiment 1. For the memory task, there was an overall reduction in the number of strategies reported when a concurrent arithmetic verification task was introduced. Participants increasingly reported Memory Reduction, coupled with a decrease in the reporting of Elaboration and Temporal Clustering, but there was no effect on

Visual Strategy reports, which was in any case reported by very few participants. There was no impact on reported use of Rehearsal.

Under AS there was a reduction in number of strategies reported, consistent with our expectation that AS would reduce the use of strategies that rely on rehearsal. Indeed, fewer participants reported Rehearsal and Temporal Clustering. A few more participants reported use of a Visual Strategy. However, as for the dual task condition, this strategy was reported by very few participants so would merit replication. In this condition there was also an increase in reports of Memory Reduction.

Dual task and AS together showed no interaction for any of the reported memory strategies. There was a reduction in reports of Rehearsal under AS but no additional impact of dual task. There was an increase in reports of a Visual Strategy under AS, but with no impact of dual task. There was a reduction in reports of Elaboration under dual task but with no additional impact of AS. These results are consistent with independent effects of AS and dual task. Temporal Clustering was reduced for both AS and dual task, and Memory Reduction was increased for both AS and dual task.

Concerning processing strategies, participants reduced their reports of Counting under dual task. This is consistent with previous studies that have explored the impact of AS on counting (Imbo & Vandierendonck, 2007; Logie & Baddeley, 1987). AS decreased the reports of Counting in the single Task, but there was no effect of AS in the dual task. In contrast, reports of Retrieval increased with AS, but were unchanged with dual task. However, again, there was no AS effect under dual task. As with the reported memory strategies, this pattern of results for arithmetic verification suggests that AS and dual task have distinct effects on the two strategies.

These results might offer some additional insight into why processing performance was unaffected by AS as reported in Doherty et al. (2019). One possibility is that switching to a retrieval strategy under AS allowed participants to maintain the same level of performance that

they also achieved using counting. The lack of an impact of dual task on retrieval might suggest that consistent use of this strategy avoids the impact of dual task, even if participants have the subjective impression that they rely less on counting under dual task conditions.

Before further discussing the implications of these results for our theoretical understanding of WM, and in order to assess how robust were the results from our strategy analyses of Doherty et al. (2019) Experiment 1, we examined the use of strategies in Doherty et al.'s (2019) second experiment.

Experiment 2

In Doherty et al. (2019) Experiment 2, the letter memoranda were presented aurally and participants recalled the items orally. This change was used to assess whether the presentation modality of the letters (either visually or aurally) induces different or additional coding during the presentation of the memoranda (e.g. Baddeley et al., 1984; Logie et al., 2000; Logie et al., 2016; Saito et al., 2008), which could in turn trigger specific strategies, such as Visual or Acoustic strategies. For example, aural presentation may result in direct phonological coding of the memoranda, which favors the use of Rehearsal (Baddeley, 1992; Baddeley, et al., 1984), whereas the visual presentation used in Experiment 1 typically involves translation to a phonological code (Conrad, 1964), but can also result in use of a visual code, particularly under AS (Logie et al., 2000; 2016; Saito et al. 2008). Therefore, the expectation is that rehearsal and acoustic strategies will be widely reported by participants, but there would be few, if any reports of visual strategies. We expected no increase in reports of visual strategies with AS, but we did expect a decrease in reports of rehearsal and temporal grouping coupled with an increase in reports of elaboration. As for Experiment 1, dual task was expected to reduce the reports of elaboration. However, for Experiment 2, the expectation was that because previous studies have suggested that aural presentation more readily leads to the use of rehearsal, then there will be an increase in the reports of rehearsal under dual task. Because there was no change in the

modality of presentation of arithmetic verification, the expectations were the same as for Experiment 1. Finally, Experiment 2 assessed how robust were our results on strategies by investigating whether or which results from Experiment 1 would replicate with a different modality of presentation and recall.

Method

Participants. Participants were 64 undergraduate students (age: $M=21.84$, $SD=2.73$), half of them from University of Edinburgh, half of them from Fribourg and Geneva Universities, with testing language and experimenter as for Experiment 1. They received financial compensation (£12) in United Kingdom, and course credit or a cinema voucher in Switzerland. They all had corrected-to-normal vision, and were informed concerning the purpose of the experiment (which was presented as a study on memory). None of them participated in Experiment 1.

Procedure. The procedure was similar to the procedure of Experiment 1 with the following changes. Letters were aurally presented using headphones, participants recalled them in serial order after a retention interval of 10 seconds by speaking out loud rather than using a keyboard, and the experimenter recorded the response on a separate keyboard. Also, because of the use of auditory presentation, AS began after the presentation of the letters to ensure that the letters were encoded phonologically before the AS started. This was important because our focus in these experiments was on retention in memory, not on encoding.

Results

Performance. As for Experiment 1, performance results are reported in detail in Doherty et al. (2019). In summary, the titration procedure led to a mean span of 6.50 ($SD=1.00$) on memory and of 8.60 ($SD=2.00$) on the addition verification task. Participants recalled fewer letters in dual-task than single-task condition (scaled effect size: -1.21). The main effect of AS

was also significant, with fewer recalled letters under AS (scaled effect size: -2.00). The performance in the addition verification task was only affected by the dual task condition (scaled effect size: -0.43), but not by AS.

Memory strategies. Six participants were excluded from the analyses on strategies, because they did not report any strategy or did not fill in the questionnaire correctly. These latter participants generally misunderstood the questions and instead reported how they felt about the task. The analyses on strategies were thus performed on 58 participants (29 from the UK, and 29 from Switzerland).

Classification of memory strategies. The same classification of memory strategies as in Experiment 1 was used to classify our participants' responses to the strategy questionnaire (Table 2). For each strategy and in each condition, each participant's response was coded 1 when s/he reported using a given class of strategy and 0 otherwise, allowing coding of the use of several strategies for each response.

Number of strategies. As in Experiment 1, the Memory Reduction strategy was not included in this analysis. A repeated measures ANOVA was conducted on the number of strategies ($M=1.39$; $SE=.08$) across conditions as within-participant factors, specifically AS (with vs. without) and Task (single vs. dual). The main effect of Task was significant $F(1,57)=21.15$; $p<.001$; $\eta_p^2=.27$ with a higher number of strategies reported in the single Task ($M=1.59$; $SE=.09$) than in the dual Task ($M=1.20$; $SE=.09$). The main effect of AS and the interaction between Task and AS were not significant ($ps>.41$).

In the single task condition without AS, all the participants reported at least one strategy, and one participant reported only the Memory Reduction strategy. In the dual task without AS two participants reported no strategies, and three participants reported only the Memory Reduction strategy. In the single task with AS, two participants reported no strategies, and one participant reported only the Memory Reduction strategy. Finally, in the dual task with AS, five

participants reported no strategies, and seven only reported the Memory Reduction strategy.

Strategy use. The same analyses were conducted as in Experiment 1 (Figure 4 and Table 3). The dual-task condition led to fewer reports of Rehearsal ($OR = .55$; $CI\ 95\% = .36, .85$). Temporal Clustering and Elaboration were less reported in dual-task than in single task conditions ($OR = .53$ $CI\ 95\% = .34, .81$; and $OR = .51$; $CI\ 95\% = .30, .87$ respectively). There was no impact of dual task on reports of Visual Strategies. However, participants reported using the Memory Reduction strategy more often in the dual-task than in the single-task condition ($OR = 4.98$; $CI\ 95\% = 2.37, 10.48$). This was also the case for the Acoustic strategy ($OR = 2.34$; $CI\ 95\% = 1.00, 5.45$). Conditions with AS led to fewer participants reporting using Rehearsal and Temporal Clustering than in the condition without AS ($OR = .48$; $CI\ 95\% = .31, .75$; and $OR = .44$; $CI\ 95\% = .28, .68$ respectively). There was no impact of AS on reports of Elaboration, Visual, Acoustic or Memory Reduction strategies. No interactions were found.

Figure 4 about here

Processing Strategies.

The same categories for the strategies on addition verification were used as in Experiment 1. Results are reported in Table 3 and Figure 5. For each strategy and in each condition, each participant's response was coded 1 when s/he reported using a given class of strategy and 0 otherwise, allowing several classes of strategy for each response.

Number of strategies. As in Experiment 1, the Processing Reduction strategy was not included in this analysis. The number of strategies ($M = 1.00$; $SE = .07$) was submitted to a repeated measures ANOVA with Task (single vs. dual) and AS (with vs. without) as within-subjects factors. The main effect of the Task was significant $F(1,57) = 6.23$; $p < .05$; $\eta_p^2 = .10$. Participants reported more strategies in the Single Task ($M = 1.09$; $SE = .08$) than in the Dual Task ($M = .91$; $SE = .07$). The main effects of AS and the interaction between the two factors were non-significant, $ps > .33$.

In the single task without AS, ten participants reported no strategies, and none of the participants reported only the Processing Reduction strategy. In the dual task without AS, nine participants reported no strategies, and three participants reported only the Processing Reduction strategy. In the single task with AS ten participants reported no strategies, and none of the participants reported only the Processing Reduction strategy. Finally, in the dual task with AS 13 participants report no strategies, and none of the participants reported using only the Processing Reduction strategy.

Strategy use. The same analyses were conducted as in Experiment 1, including the Processing Reduction strategy. For Counting, the interaction between Task and AS was significant, so a factorial model was preferred. The main effects of Task, the main effect of AS and their interaction were significant. In single-task conditions, participants reported using Counting more often in the condition without AS than with AS ($OR = .42$; $CI\ 95\% = .26, .66$). In the dual-task conditions, the percentage of participants reporting using Counting did not differ between these two conditions ($OR = .79$; $CI\ 95\% = .52, 1.19$). For Retrieval, the interaction between Task and AS was not significant, $p = .19$, so this led us to prefer the additive model. Retrieval was reported more often in the dual- than the single-task conditions ($OR = 2.01$; $CI\ 95\% = 1.31, 3.09$). The effect of AS was not significant, $p = .27$.

Figure 5 about here

Cross-experiment analyses. One aim for these experiments was to investigate whether changes in the modality of presentation of the memory items would impact the type of strategy that participants report. Presenting verbal memory items aurally should favor their encoding in a phonological format and their maintenance by Rehearsal, while their visual presentation would require the recoding into a verbal code to be rehearsed, and might also include the use of visual codes. Hence, we performed a series of cross-experiment comparisons to examine whether the use of the different strategies, and in particular the use of Rehearsal, varied across

experiments. We report in the following section only the variations of the studied effects across experiments (i.e., interactions with Experiments only).

A GEE was performed on each memory strategy with Task (single vs. dual), AS (with vs. without) and Experiment (Exp. 1 vs. Exp. 2). A full factorial model was systematically tested first. If the interactions terms with Experiment were not significant, a model including the main effects and the Task x AS interaction was preferred. If none of the interaction terms were significant, an additive model was tested.

For Rehearsal, Temporal Clustering, Elaboration and Memory Reduction, the same pattern of findings emerged. The main effect of Experiment was never significant, $ps > .32$. None of the interactions were significant, $ps > .11$, and the additive model with the main effects of Task and AS was preferred. For the two last strategies, Visual and Acoustic, the additive model was also preferred, because no interaction terms were significant, $ps > .14$. But, contrary to the other strategies, the main effect of Experiment was significant for Visual and Acoustic strategies. The visual presentation of letters in Experiment 1 led to fewer reports of using the Visual ($M = .08$, $SE = .02$) and Acoustic ($M = .02$, $SE = .01$) strategies than with the auditory presentation of letters in Experiment 2 ($M = .22$, $SE = .03$ and $M = .12$, $SE = .02$, respectively), Wald $Z = 6.67$, $p < .01$, $OR = .33$ with $CI_{95} = [.14, .76]$, and Wald $Z = 6.04$, $p = .01$, $OR = .15$ with $CI_{95} = [.03, .68]$, respectively.

The same analyses as for the memory strategies were conducted for the processing strategies. However, the number of participants reporting Processing Reduction was too low to perform an analysis on this strategy. For Counting and Retrieval, the pattern was similar. For both strategies, the main effect of Experiment was non-significant, and all interaction terms including Experiment were not significant, $ps > .05$.

Discussion

The aim of the analyses of reported strategies in Experiment 2 was twofold. First, Experiment 2 allowed us to examine whether a change in modality of the presentation of the memory items would impact the choice of strategies, and second we wanted to assess how robust were the results of Experiment 1. Broadly, the results in Experiment 2 replicated those in Experiment 1, a conclusion that was reinforced by the cross-experiment comparisons. One difference between the two experiments affected the use of two particular strategies, Visual and Acoustic. More participants reported the use of the acoustic strategy when the memory items were presented aurally (Exp. 2) than visually (Exp. 1). This is consistent with the idea that participants favored phonological coding of the letters in Experiment 2. Unexpectedly, a similar pattern occurred for Visual Strategy, with a higher percentage of participants reporting use of this strategy in Experiment 2 than in Experiment 1. A possible explanation is that some participants reported using the keyboard as a visual cue to remember the letters, in addition to some participants reporting that they visualized the appearance of the aurally presented letters. When letters were presented through headphones in Experiment 2, it was easier to look at the keyboard to support memory (e.g. Darling, Allen, & Havelka, 2017), or to visualize the letters (Brooks, 1967; 1968) than when the letters were presented visually on screen in Experiment 1. However, Visual and Acoustic strategies were reported by relatively few participants, so a formal analysis was not possible, but future studies might address these strategies more directly.

Also, in line with Experiment 1, counting for arithmetic verification was reduced by concurrent articulation and by dual task. Dual task resulted in an increase in reports of retrieval, but AS did not.

Finally, as in Experiment 1, and as expected according to previous findings in mathematical cognition, the number of memory strategies was reduced under the dual-task condition. However, unlike Experiment 1, AS did not reduce the overall number of strategies reported.

Taken together, the results of Experiments 1 and 2 support the idea that participants change the strategies that they use to perform memory and processing tasks under different experimental conditions. Nonetheless, one important limitation in these two experiments is that participants were asked about their strategies only after they had completed all conditions within each experiment. This was essential to ensure that reporting strategies did not affect subsequent performance. However, the reports that we obtained do not distinguish between participants who used the same strategy throughout a given experimental condition (e.g. rehearsal in single task without AS), and those who spontaneously changed their strategies across trials within a condition. We also do not know if the same actual strategy was used by different participants even when they used the same words to describe their strategy. Moreover, some participants might have felt obliged to describe one or more strategies because they were asked to do so, even if they were not wholly aware of how they were performing the tasks in each condition. Although there were clear shifts in the number of participants reporting each kind of strategies, it is striking that only 55% of participants reported using some form of rehearsal in single task memory without AS, raising the question as to how the other participants were performing the task, although some participants reported more than one strategy. Finally, although some participants reported several strategies, others were unable to report any strategies.

Interestingly, in these two first experiments, we did not find any link between the reported use of strategies and the task accuracy. This lack of a link could be due to a compensatory mechanism, namely changing strategies to maintain a constant level of performance. It could also be due to the fact that we used a final report to assess strategies. Final reports may lead participants to report an average of the strategies they used across the trials of a given condition, which could obscure a potential relationship with accuracy.

To respond to these limitations, we performed a third experiment using a trial-by-trial report². The use of a Likert scales at the end of each trial provided converging evidence for the conclusions of Experiment 1 and 2 by using a different procedure. Moreover, this new procedure also allowed us to avoid the possible use by participants or different words to describe a given strategy, as might have been the case in Experiments 1 and 2 that used free reports. It is to be noted that the requirement to report strategies trial by trial in itself might act as a dual task and might affect how the task is performed (for opposing views see Ericsson & Simon, 1984; Nisbett & Wilson, 1977). Nonetheless comparing the results on performance of this third experiment with the first two experiments should allow us to assess whether reported strategies and/or performance differ when participants are asked to report trial by trial.

Experiment 3

This third experiment was similar to Experiment 1, but with a trial-by trial assessment of the strategies instead of a final report. The goals of this experiment were 1) to evaluate the robustness of our results on strategies by using another method to measure them 2) to use a method allowing a better assessment of the link between the reported strategies and the actual performance. We expected to observe the same strategic adaptation as before, but with a more fine-grained analysis.

Method

Participants. Participants were 61 undergraduate students (age: $M=$, $SD=$), 29 of them from University of Edinburgh (United Kingdom), and 32 of them from the Clermont Auvergne University (France). In this case the language was appropriate for each country, but the experimenter, who was bilingual, was the same (CB). Participants received financial compensation (£12) in United Kingdom, and course credit in France. They all had corrected-

² We thank anonymous reviewers of an earlier version of this manuscript for suggesting this additional experiment

to-normal vision and were naive concerning the purpose of the experiment (which was presented as a study on memory). None of them participated in Experiment 1 or 2.

Procedure. The procedure was similar to the procedure of Experiment 1 with the following changes. At the end of each trial of the experimental blocks (but not during the titrations), participants were asked about the strategies they used using 5-point Likert scales. Based on the two previous experiments, the following memory strategies were assessed: Rehearsal, Temporal Clustering, Elaboration, Visual, Acoustic and Memory Reduction. We also assessed 3 processing strategies: Counting, Retrieval and Processing Reduction. For example, for the rehearsal strategy, participants were asked: “to what extent did you repeat the letters (aloud or in your head)?” and had to answer on a 5-point scale going from 0% to 100%. The English wording of all the scales is presented in annex A. The French version was a direct translation by the first author (CB) who is a French native speaker. Moreover, at the beginning of the first memory single task each memory strategy was introduced by a short text describing it. Similarly, the processing strategies were introduced at the beginning of the first processing single task (see Annex A for the English wording of these texts).

Finally, because the evaluation of the strategies at the end of each trial greatly extended the duration of the experiment, we reduced the number of trials. After the titration procedure for memory and processing, participants performed 6 trials of the memory single task and 6 trials of the processing single task (instead of 10 trials for each task in Experiment 1). They then performed 12 trials of the dual task (instead of 20 trials in Experiment 1). Finally, they were again presented with 6 trials of the memory single task and 6 trials of the processing single task (instead of 10 trials for each task in Experiment 1). As for Experiment 1, the procedure was repeated twice, once without articulatory suppression (AS), and once with AS.

Results

Performance. We used similar analyses to those for Experiments 1 and 2, namely

logistic mixed effects regression using the R package lme4 (Bates, Mächler, Bolker, & Walker, 2015) allowing the use of log odds of a correct response as the dependent variable while modelling repeated measures. Full models were first assessed for memory and processing performance, including the two main effects and their interaction plus a random intercept for each participant. The factors entered in the model were: the effect of the task (single *vs* dual task) and Articulatory Suppression (without *vs* with). We then compared the full models with simpler models in which the interaction was removed, by using BIC values (Schwarz, 1978). The main effects were then considered in separate models. At each step of the model comparison, a Bayes factor was computed to decide whether the simpler model should be retained or not. The simpler model was always preferred except when the Bayes Factor was clearly against the removal of the effect considered (i.e. >3).

The results replicated those of Experiment 1. The titration procedure revealed a mean span of 6.34 (SD=1.22) on the letter memory task and of 6.87 (SD=2.0) on the addition verification task. Concerning memory performance, the best model included the main effect of the Articulatory Suppression (scaled effect size = -1.52), with fewer letters recalled under AS, and the main effect of the Task (-0.33), with fewer letters recalled in the dual task than in the single task. The null model was retained concerning the processing performance that was affected neither by the Articulatory Suppression nor dual task.

Memory strategies.

Number of strategies. In Experiment 3, participants answered on a 5-point Likert scale on the extent to which they used each strategy with answers going from 0% to 100%. Consequently, to compute the number of strategies reported to be used on each condition, we took into account any strategy reported to be used at least to some extent (namely 25%, corresponding to the second point of the scale). As in Experiments 1 and 2, the Memory Reduction strategy was not included in this analysis.

The overall number of strategies reported to be used at least to some extent (overall: $M=3.61$; $SE=.07$) was higher than the number of reported strategies observed in Experiment 1 ($M=1.03$; $SE=.06$), consistent with the hypothesis that trial-by-trial reporting might offer a more fine-grained analysis. Alternatively, having more clear options in the rating procedure, might have resulted in such a higher number of reported strategies. The number of reported strategies was analyzed by using a repeated measures ANOVA with AS (with vs. without) and Task (single vs. dual) as within-subject factors. As in Experiment 1, participants reported using more strategies in the single task ($M=3.80$; $SE=.12$) than in the dual task ($M=3.43$; $SE=.12$) $F(1,60)=19.38$; $p<.001$; $\eta_p^2=.24$. However, neither the effect of Articulatory Suppression (AS) nor the interaction between the Task and AS were significant.

Strategy use. The answers to the Likert scale were treated as ordinal variables rather than continuous ones (Liddell & Kruschke, 2018), and were analysed using Bayesian Regressions with a Cumulative Model (Bürkner & Vuorre, 2019) implemented in the BRMS package in R. For each strategy, the scoring was entered as a dependant variable with the Task (single vs dual), AS (without vs with articulatory suppression) and their interaction as predictors plus a random intercept for each participant. The full model was then compared to simpler models without the two-way interaction by using approximate leave-one-out cross-validation (LOO; Bürkner & Vuorre, 2019). The models indicated that, as in Experiment 1, AS reduced the reported use of the Rehearsal (scaled effect size = -1.56) and the Clustering (-0.93) strategies. It also reduced the reports of the Acoustic strategy (-1.04), an effect we did not find in Experiment 1, probably because few participants indicated that they used it. Moreover, and more surprisingly, the Elaboration strategy was slightly less reported under AS (-0.11) but did not change according to the task contrary to what we observed in Experiment 1. In contrast, the Visual (0.79) and the Memory Reduction (1.81) strategies were more reported with than without Articulatory Suppression in this experiment as well as in Experiment 1. Concerning the effect

of dual tasking, the Rehearsal (-.27) and the Clustering strategies (-.24) were less reported in the dual task than in the single task, whereas the reports of the Memory Reduction strategy, in contrast, increased (0.50). Experiment 1 produced similar results on the Clustering and Memory Reduction Strategies, but not on the Rehearsal strategy.

Two of the winning models included the interaction between AS and the Task. The effect of AS was smaller in the dual task (0.24) for the Clustering strategy, but larger for the Memory Reduction Strategy.

Finally, as suggested by a reviewer, we looked at potential differences in the reports of the strategies between participants that began under articulatory suppression and participants that began without articulatory suppression. No noticeable difference were observed between the two orders (See Supp Text S2, Figure S1 and Figure S2).

In summary (see Figure 6), we replicated most of the effects observed in Experiment 1 but with slight differences probably due to the fact that the participants reported a higher number of strategies in general, allowing finer grained observation of the different variations according to the experimental manipulations.

Figure 6 about here

Strategy and performance. Spearman's correlations between each strategy and the performance on memory were first performed. The results (Table 6) indicated that all the strategies positively correlated with the memory performance, with the exception of the Visual strategy, and the Memory Reduction strategy that correlated negatively with the performance. Interestingly, the rating of these two strategies also correlated negatively with the rating of the Rehearsal, Temporal Clustering and Elaboration strategies, consistent with the idea that participants shifted to the Visual and Memory Reduction strategies when the difficulty of the task increased and that, consequently, the performance dropped.

Table 6 about here

We analyzed the memory performance again, by using logistic mixed effects regression using the R package lme4 with the effect of the task (single vs dual task), the Articulatory Suppression (without vs with) and the type of Strategy (Rehearsal, Temporal Clustering, Elaboration, Acoustic, Visual and Memory Reduction) as factors, following the same rationale for model simplification than when the performance was analysed without taking the strategies into account. The model that was selected did not include the main effect of strategy, nor an interaction between the strategies and the other factors.

Processing strategies.

Number of strategies. As for memory strategies, we took into account any strategy reported to be used at least to some extent (25% corresponding to the second point of the scale) to compute the number of strategies reported being used on each condition. As in Experiments 1 and 2, this number does not include the Processing Reduction strategy. Overall, the participants reported using on average 1.93 strategies ($SE=.02$) over the two that were measured (Counting and Retrieval), indicating that most of the participants always used these two strategies (at least to some extent). As for the memory strategies, a repeated ANOVA was performed with AS (with vs. without) and Task (single vs. dual) as within-subject factors. Similarly to what was found in Experiment 1, participants reported using slightly more strategies in the single task ($M=1.95$; $SE=.03$) than in the dual task ($M=1.91$; $SE=.03$) $F(1,60)=5.36$; $p=.02$; $\eta_p^2=.08$, while neither the AS or the interaction reached significance ($p>.05$).

Strategy use. The same analyses were performed as for the memory strategies. The selected models indicated that, as in Experiment 1, AS led to a reduction in the reports of the Counting strategy (-0.42) but to an increase of the reports of the Retrieval strategy (0.16). A similar pattern was observed for the effect of Task, with fewer reports of the Counting strategy (-0.38) in the dual task than in the single task, but slightly more reports of the Retrieval strategy

(0.06). Taken together, these results (Figure 7) are similar to those of Experiment 1. Moreover, the Processing Reduction strategy was reported more often under AS (0.14), and in the dual task rather than in the single task (0.48). The model for this strategy included an interaction (.41) indicating that the effect of the Task was observed only when AS was absent.

Figure 7 about here

Strategy and performance. Spearman's correlations (Table 7) indicated that the Counting and the Retrieval Strategies both correlated positively with the performance on processing. In contrast, the Processing Reduction strategy negatively correlated with the performance. Interestingly, the Counting and the Retrieval strategies negatively correlated with each other at -.44, probably indicating a tradeoff between these two strategies. The Processing Reduction strategy was negatively correlated with the two other strategies, which is probably due to the fact that, as for the memory strategies, the Reduction strategy was used when the task became too difficult for participants. It is however interesting to note that the Memory Reduction strategy was more often reported than Processing Reduction, a phenomenon we also observed on Experiments 1 and 2.

Finally, the processing performance was analyzed using logistic mixed effects regression, as for the memory performance. The winning model did not include any effect of the strategies or their interactions with the Task or AS.

Table 7 about here

Discussion

Experiment 3 was a replication of Experiment 1, but with a trial-by-trial assessment of the strategies instead of a final report. Our goals were to evaluate the extent to which the results we found in the two first experiments were due to the kind of assessment used, and whether the

939 strategies observed on the previous experiments were linked with changes in the performance
940 level.

941 A first important point to notice is that, in spite of the changes we have introduced
942 compared to Experiment 1 (namely a questionnaire on the strategies used at the end of each
943 trial and 6 trials per block instead of 10), our results for the performance level are remarkably
944 similar to those of Experiment 1. Performing a dual task at their own level in memory and
945 processing reduced the performance of the participants on memory but not on processing. This
946 is reassuring because it suggests that the introduction of the trial-by-trial assessment did not
947 impact the performance of the participants. Nonetheless, this experiment allows us to be more
948 confident about the conclusions from the two first experiments. The constraints of dual-tasking
949 and of articulatory suppression are not only observed in the performance levels, but also in the
950 way in which the participants carry out each task in each experimental condition.

951 With respect to the range of different strategies used by participants, Experiment 3
952 showed that participants reported less use of memory and processing strategies in the dual task
953 than in the single task, a result that we also found in Experiments 1 and 2. However, we did
954 observe an effect of AS in Experiment 1 only (but not in Experiments 2 and 3), which casts
955 doubt on the robustness of this result. Altogether, the results of the three experiments point to
956 distinctive effects of dual tasking and AS. That is, the number of reported strategies was reduced
957 by the introduction of a second task, not by AS.

958 Concerning the memory strategies, most of the effects observed in Experiment 1 were
959 replicated in Experiment 3. For instance, AS reduced the reports of Rehearsal and Clustering
960 strategies, but increased the reports of the Visual and the Memory Reduction strategies.
961 Moreover, the Clustering strategy was less reported in dual task than in single task while the
962 opposite was true for the Memory Reduction Strategy. However, the effect of the Task on
963 Elaboration that we observed in Experiments 1 and 2 was not replicated here, this strategy being

only slightly less reported under AS. Finally, the acoustic strategy that was hardly ever reported in Experiment 1 was much more often reported in this experiment, which made it possible to observe a decrease in the reports of this strategy under AS. This reduction seems to indicate that the acoustic strategy is based on the phonological loop, which is disrupted by AS. Once again, the results on Memory Reduction are interesting. Under what might be considered the most demanding condition, namely dual task under AS, our participants reported that they did use Memory Reduction to some extent in 73 percent of the trials. In other words, our participants really did the task as we expected in only 27 percent of the most critical trials. We will return in the general discussion to the importance of these results for the Memory Reduction strategy, which we observed in our three experiments.

The reports on the processing strategies were also broadly similar to those of Experiment 1. AS and the introduction of a secondary task led to a reduction in the reports of the Counting strategy, and to an increase in the reports of the Retrieval strategy. The Processing Reduction strategy was more often reported under AS and in the dual task, but never to the extent of the Memory Reduction strategy, suggesting that, in the dual-task situation, participants preferred to focus on the processing rather than on the memory.

Finally, another goal of this experiment was to assess the link between the reported strategies and the performance. Here our results are mixed. On one hand, we did observe that some memory strategies (Rehearsal, Clustering, Elaboration, Acoustic) as well as some processing strategies (Counting, Retrieval) were positively correlated with performance. Moreover, the reports of these strategies were also negatively correlated with the report of other strategies (for memory: Visual and Memory Reduction; for processing: Processing Reduction) that are themselves negatively correlated with performance. Combined with what we observed on the strategy reports, this pattern suggests that, under difficult conditions, participants might shift toward less costly but also less efficient strategies. But on the other hand, when the

strategies were entered in a model to explain performance, they did not appear as significant predictors. A possibility is that we lack statistical power to correctly assess this link, and more work is probably needed on this particular point.

General Discussion

Obtaining widespread agreement among researchers regarding the understanding of how WM facilitates concurrent storage and processing has proved to be a challenge for several decades. Two broadly contrasting conceptions have been developed; either that the two activities are relying to some degree on the same general resource that needs to be shared, as assumed by a range of theories, notably Embedded Processing (Cowan, 2016) and Time-Based Resource-Sharing (Barrouillet & Camos, 2015), or that each activity can be supported by different sub-systems as assumed by Multiple Component Models (Baddeley & Logie, 1999; Logie, 2016). A major motivation for the current study was that none of the three models of WM considered by the current authors could account for all of the performance data in two experiments reported by Doherty et al. (2019) that were designed to test the different predictions of each of these models. This approach of directly comparing the predictions of three different, well supported WM theories using exactly the same experimental paradigms run in parallel across two labs had not been attempted before, as far as we are aware, and so the lack of clear theoretical closure that was obtained was always a possible outcome. But it highlighted the need to consider alternative approaches that could capitalize on the research collaboration rather than pursuing the more traditional practice of attempting to discriminate between competing theories. Our hypothesis in the current paper was that this lack of theoretical closure might be resolved by considering the strategies that participants reported adopting in response to the different experimental manipulations. This raised the possibility that evidence for differential strategies among participants might reflect the use of different cognitive functions, and this in turn might lead to a theoretical resolution based on integrating the theories rather than taking

the more common approach of favoring one theory at the expense of the others. To our knowledge, the present study is the first one to examine this long-standing issue of dual-task effects in WM through the investigation of strategy use and strategic adaptation for both memory and for a concurrent processing task. Performance in itself is not the mere reflection of the capacity of a cognitive system, but reflects the way individuals use the available cognitive functions at their disposal within that capacity. As extensively shown in the study of mathematical cognition and cognitive development by Siegler (1987; 1995 for a review; Fazio et al., 2016), examining performance without taking into consideration the involved strategies could lead to misinterpretations (see Logie, 2018, for similar arguments in WM). In other aspects of WM, studies have demonstrated that participants change strategies across tasks, and that different participants may use different strategies for the same task (e.g. Logie et al. 1996; Morrison et al., 2016). Here, we first discuss the consistent results from this investigation observed in the three experiments, and their theoretical implications. Then we consider data patterns for reported strategy use that were specific to one or other of the experiments.

It was clear from the results that we report in the current manuscript that the observed reduction in memory performance under dual task compared with single task conditions in the three experiments reported here (but see Doherty et al., 2019, for a complete analysis of performance data from the two first experiments) was accompanied by complex, but systematic changes in the reported strategies. Specifically, the introduction of simple arithmetic verification during a retention interval resulted in fewer participants reporting the use of Temporal Clustering strategies, and more participants reporting use of a strategy (Memory Reduction) that reduced the number of items that participants attempted to retain in memory. Moreover, in Experiments 1 and 2, the Elaboration strategy was less reported in the dual task than in the single task. These results are consistent with all three models of working memory that we considered. They can be interpreted by assuming that the arithmetic verification task

shares at least some of the same resource as is required for Elaboration and Temporal Clustering of the memory items when memory load is close to span. For EP and TBRS, this is referred to as limited capacity attention. For MCM, this is a processing resource that can also provide partial support for memory as argued in Doherty and Logie (2016). Consistent with this interpretation, we observed a reduction in the number of different strategies reported being used in the dual task compared to the single task in all three experiments.

The introduction of articulatory suppression (AS) resulted in fewer participants reporting use of Rehearsal and Temporal Clustering, but no change in reported use of Elaboration to support memory. These results also are consistent with all three theories of working memory that we considered. All three theoretical perspectives accept that AS disrupts the use of subvocal rehearsal of a sequence of verbal items, so can readily account for the impact of AS on reported Rehearsal and Temporal Clustering strategies. Both TBRS and MCM assume that subvocal rehearsal involves a separate system that does not require a domain-general cognitive resource. EP assumes that there is an initial demand on limited capacity attention when AS starts, but not thereafter (Naveh-Benjamin & Jonides, 1984), and so would not expect AS to have an impact on strategies that are assumed to demand attention, specifically Elaboration.

Unlike memory performance, in the three experiments, performance on the arithmetic verification task showed little or no disruption when concurrent with a verbal memory load, and was unaffected by AS. From these results, we might expect no change in strategies across conditions. Nonetheless, there were clear changes in reported strategies observed. A first point to notice is that the introduction of a memory task led to a reduction on the number of strategies reported for the processing task in our three experiments, which suggests a reduction of the cognitive flexibility of our participants. Specifically, in all three experiments, a Counting Strategy was reported less frequently with a concurrent memory load, and with AS. The

interaction between dual task and AS observed in Experiments 1 and 2 (Figures 3 and 5) could be explained on the grounds that a dual task may interfere with the start of rehearsal (Naveh-Benjamin & Jonides, 1984), whereas AS interferes with both the start and with continuing rehearsal. However, this interaction concerning the Counting Strategy should be interpreted with caution given that it was not replicated in Experiment 3. The alternative, direct Retrieval strategy showed a less consistent pattern. In Experiments 1 and 3, AS resulted in an increase in reported use of Retrieval, although in Experiment 1 it was only the case in the single-task condition. These results are consistent with all three theories given the assumption that the memory load would be maintained by rehearsal, and therefore would have a similar effect to that found with AS. Adding AS to a concurrent memory load would then have no additional impact on the reports of the retrieval strategy. However, participants might increase the use of Retrieval to compensate for the reduction in the use of Counting. In Experiments 2 and 3 reports of Retrieval increased with a concurrent memory load. Altogether, these results suggest at the very least the impact of demanding conditions such as a memory load or AS might lead to a shift from the Counting Strategy to the Retrieval Strategy, as also suggested by the negative correlation between them.

Taken together, these results demonstrate that individuals can strategically adapt to changing experimental conditions, and that this adaptation occurred not only for memory, but also for processing. Moreover, our results have led to important new insights in that there is evidence for changes in reported strategies even when performance did not change across experimental manipulations, as well as when performance changes were observed. When observing no change in performance as a result of experimental manipulations, as Doherty et al. (2019) found for arithmetic verification, there could be the misleading conclusion that there is no impact on the cognition of the participants. Examining reported strategies revealed that this was not the case for the experiments that we considered. There is evidence, not only from

Experiments 1 and 2 derived from Doherty et al. (2019) but also from Experiment 3 using a trial-by-trial evaluation, that participants adapted the way in which they performed the experimental tasks. In the case of arithmetic verification, this adaptation offers an explanation why participants showed little or no impact on performance when concurrent with a memory load and under AS. Moreover, the results for memory strategies revealed a possible reason why participants' performance was reduced by dual task and by AS. It might be that the constraints imposed by the experimental manipulations resulted in reduced performance, and participants changed strategies in order to minimize the impact of those constraints even under the most demanding experimental manipulations. Although each of the theoretical perspectives could provide an explanation for the results observed, one clear outcome was that it was not necessary to make theoretical assumptions in order to understand the underlying drivers for changes in performance levels across conditions. An account could be derived from considering what kind of cognitive resource would be needed to use each kind of strategy, and from considering how a given strategy might support performance of each task in each condition.

Theoretical Integration?

In the Doherty et al. (2019) report, it was clear that none of the three models of working memory considered could account for all of the performance data patterns. This was also true for some related experiments from the same research team reported by Rhodes et al. (2019). This suggests that the traditional approach of eliminating theories that do not fit the data and retaining a theory that does, may not be the most fruitful approach when dealing with broad theoretical frameworks. An alternative would be to adopt a more extreme position of abandoning all three theories and seeking an alternative that we did not consider explicitly when designing the experiments. However, this too might not be the best approach, given that all three models can each point to large volumes of previously published data consistent with their

associated assumptions and predictions. It also could be argued that an account based entirely on careful task analysis and strategy analysis describes the data rather than offering a theoretical framework that might generalize beyond the paradigms used here. A more positive approach might be to consider developing a new theory of working memory that is more integrative rather than adversarial, that incorporates features and assumptions drawn from all three models. We might then consider whether such a new theory might account for the data patterns that have been the focus of the current study, and have the potential to address apparently contrasting data patterns that have accumulated with the development of each model. Detailed development of such a new model is beyond the scope of the current paper (see discussion in Logie et al., 2021b), but we propose that our analyses of strategies offers a possible path to pursuit of this goal.

The observation of strategy adaptation has allowed us to conclude that the MCM, EP, and TBRS models are perhaps more compatible than might have been assumed from the performance data. Most notably, the assumption by TBRS that subvocal rehearsal can be used as a verbal memory maintenance mechanism that does not demand attention is very similar to the concept of subvocal rehearsal within a phonological loop in MCM (Baddeley, et al., 1984). Indeed, recent developments in TBRS refer to a phonological buffer combined with an articulatory rehearsal mechanism (e.g. Barrouillet & Camos, 2015; Camos, Lagner & Barrouillet, 2009). This common approach readily accounts for the effects of AS on the reported use of Rehearsal and Temporal Clustering strategies, and fits neatly with the reduction in memory performance with AS. EP has indicated that there may be peripheral components of WM, notably a verbal buffer together with an automated rehearsal system that does not require much attention (e.g. Cowan, 1988; Cowan et al., 2014), compatible with the current assumptions of the other two models.

Our investigation here indicated that there were some participants who reported using visual strategies to support memory, and there were differences in reported strategies between visual presentation used in Experiment 1 and aural presentation used in Experiment 2. Moreover, in Experiment 3, participants reported using a Visual strategy more often under AS. The recent version of TBRS includes the concept of a visuo-spatial buffer (Barrouillet & Camos, 2015, pp. 118-120), that might support temporary passive memory for the use of visual strategies. This is consistent with the concept of a visual cache (Logie, 1995) that can store visual codes that are subject to decay over a few seconds and are replaced by subsequent stimuli (Shimi & Logie, 2019). In the Logie (1995) proposal, maintenance of the material in the visual cache was thought to be supported by an inner scribe mechanism that could mentally ‘redraw’ the contents of the cache. There was no explicit discussion of the exact nature and cognitive resource requirements of the inner scribe in Logie (1995), although other studies have demonstrated that retention of visual codes is more readily disrupted than is retention of phonological codes in the phonological loop of MCM (e.g. Phillips & Christie, 1977; Salway & Logie, 1995). This suggests that maintenance of the information in the visual cache to prevent decay or interference from new material requires some domain-general resource for the inner scribe concept. TBRS has argued that maintenance of visual codes requires a central shared attentional resource and that there is not a specific mechanism for doing so. Both approaches would be consistent with the reports of visual strategies, but the vulnerability to disruption would lead to a drop in memory performance in response to AS or dual task, even when visual strategies are available. However, only a small percentage of participants reported use of visual strategies. To be consistent with these ideas, EP might consider including a temporary, limited capacity visual buffer as a peripheral component. Whether that component is essentially activated LTM visual representations or a domain-specific system that is separate from LTM

does not actually matter for the concept of a visual buffer to have explanatory utility, though activated LTM would presumably require some attention for maintenance.

The integration of the models might at first have appeared very challenging given the MCM assumption that there is no attentional resource to share, and the assumption from TBRS and EP that when two tasks are performed concurrently, they will share a limited capacity system and the extent to which this affects performance will depend on the overall load on attention. However, our arguments above regarding MCM suggest that there can also be sharing of a cognitive resource to implement a given strategy. Several previous dual task studies within the MCM framework have reported, and acknowledged, both domain general and domain-specific contributions to performance (e.g. Baddeley & Hitch, 1974; Logie, Zucco, & Baddeley, 1990; Salway & Logie, 1995), and the strategy analysis demonstrated how strategy adaptation could mitigate the impact of this sharing between two tasks performed concurrently. The strategy analysis, then, offers a theoretical bridge between theories. The remaining debate is then the nature of this shared resource rather than whether or not there is such a resource.

Some very recent experimental work by Barrouillet, Gorin and Camos (2021) has taken this theoretical integration further by introducing what they refer to as a maxispan procedure. In those experiments, participants were presented with sequences of between 4 and 11 letters for immediate serial ordered recall. In one condition, participants were simply asked to try to remember all the letters. In a second condition participants were instructed to rehearse aloud only a subset of each list, and to remember the other items in any way they could. For example, they might be asked to rehearse only four items from a seven item list. Results were clear in showing that when asked to rehearse only a subset of items, participants could recall on average one extra letter from each list compared with when they were given no specific instructions. Results were interpreted to suggest that when items are explicitly rehearsed aloud, this uses the maximum capacity of around four items in the phonological store, and that other items were

being retained by means of a shared, general resource. Without explicit rehearsal instructions, participants may not be using the full capacity of each system that can support memory. Therefore, when measuring span by the maxispan method, the typical span letter of six approached a span of eight letters. This can be interpreted to reflect the operation of two aspects of cognition that contribute to performance, namely a temporary verbal memory store with a capacity of four items, combined with an additional general resource that can retain the remaining four items. This finding that arose from the TBRS perspective is consistent with assumptions of MCM about the use of multiple resources that act in concert to support performance. The finding can also be seen as consistent with the EP assumption of a capacity of four items for the focus of attention as a general resource coupled with what Cowan et al, (2014) referred to as a peripheral component of working memory that might also have a capacity of four items.

The suggestion that there are two systems in WM that contribute to verbal memory performance might also offer an account for the residual levels of memory performance even under conditions of high cognitive load. In most dual task studies, even when there is a large impact of dual task, memory performance rarely, if ever drops close to zero, suggesting that there remains a cognitive resource that is not completely shared across the tasks that are combined (Belletier et al., 2020; Logie et al., 2021b). For example in the Doherty et al. (2019) experiments, even under dual task and AS, mean performance did not drop below two letters recalled in the correct order from the sequence for recall. With a stimulus set of 18 items, the chance level for recalling two items in the correct order is very close to zero. One key difference between the three theoretical frameworks considered here is one of emphasis rather than substance. Specifically, EP and TBRS tend to focus on the observation of a drop in performance under dual task conditions. In contrast, MCM tends to focus on why, even under demanding conditions, there is a residual level of memory performance. Our analyses of reported strategy

adaptation have offered an explanation for this residual performance under demanding experimental conditions. It was notable that many participants reported the Memory Reduction strategy in which they chose to remember only some of the letters presented. One possibility is that this allows for the use of one of the two systems in WM proposed by Barrouillet et al. (2021) that can support memory for around four items, and that is not affected by the experimental manipulation (see Camos, Mora & Oberauer, 2011 for a similar argument; see Camos, 2017, for a review). Specifically, under dual task there would be the availability of the phonological loop and subvocal rehearsal. Under AS there would be a general cognitive resource available. If, in addition, we assume as in the EP model, that there is activation of LTM representations of the presented letters, then recall based on those activations would support memory for a small number of items, even when the general cognitive resource and articulatory rehearsal are not available. This activation is assumed to include rapidly-memorized information from the trial itself (Cowan, 1999). This assumption of activated LTM contributions to immediate serial ordered verbal recall would be consistent with both TBRS (Barrouillet et al., 2004; Barrouillet & Camos, 2015; Camos et al., 2018a; Camos & Portrat, 2015) and with MCM (e.g. Hulme, Maughan, & Brown, 1991; Hulme, Roodenrys, Brown, & Mercer, 1995; Shimi & Logie, 2019; Logie, 2016). This reinforces the importance of considering the Memory Reduction strategy when exploring performance changes in memory under high cognitive load. As a reminder, in Experiment 3, during the dual task combined with AS, our participants reported trying to recall all the presented letters in only 27% of the trials and reported giving up on all the letters in 25% of the trials.

A similar argument for Memory Reduction has been made with regard to immediate memory for visual information. Atkinson et al. (2017) showed that participants performed significantly better in a visual WM task when they focused on a subset of items (see also Adam, Vogel & Awh, 2017). Thus, whatever the type of WM tasks participants perform, they can

adapt the memory load of the task. Hence, examining dual-task costs without considering the actual number of items participants choose to retain could lead to biased conclusions. For example, the lack of effect of the dual task on the processing task that we observed in our three experiments might be simply due to the fact that participants prioritize the processing over the memory and give up on the letters (Belletier et al., 2020). This adds to the arguments that considering participant strategies is important to gain a full insight into what determines changes in performance as a result of experimental manipulations.

Limitations and Future Directions

We have argued that exploring reported strategies reveals important insights that help account for patterns of performance data that are otherwise difficult to interpret. We have also argued that the insights from strategies can help towards integrating theories, focusing on their common features rather than their differences. Interestingly, the results that we observed in Experiments 1 and 2 that used final reports and the one we observed in Experiment 3 that used a trial-by-trial assessment of the strategies are remarkably similar. Nonetheless, participants reported a higher number of different strategies in Experiment 3, consistent with the idea that a trial-by-trial approach offers a more fine-grained analysis. The simple fact that we used a rating scale rather than free reports might have helped participants to remember more strategies. It is notable that the results on performance did not vary in Experiment 3 compared to Experiment 1, suggesting that the assessment of the strategies on a trial by trial basis did not impact the way that the participants performed the task.

In the 3 experiments reported in this paper, we collected data in different countries (UK, Switzerland and France). However, given the variability of the answers on strategies, a much larger sample would be necessary to properly test the differences between the sites. The fact that all our experiments involved different samples, yet show similar results, nonetheless indicates that such differences are marginal at best.

One approach might be to consider strategy adaptation at the level of individual participants. For example, did the same individuals who reported rehearsal in single task memory without AS, then shift to reporting Elaboration, Memory Reduction, or Visual Strategies with AS? Were the participants who reported Elaboration strategies also the participants who showed the largest impact of dual task on memory performance? We attempted to explore these individual differences but did not have a large enough sample to allow a systematic investigation or analysis. This would merit investigation in future studies. Future studies could also investigate the impact on performance of instructing participants to use specific strategies in single and dual task, with and without AS as has been used in training strategies for working memory span (e.g. McNamara & Scott, 2001; Turley-Ames & Whitfield, 2003). Instructing a participant to use a strategy that he or she would not have spontaneously used might be counterproductive and impair rather than improve performance. However, Chooi and Logie (2020) have shown that examining strategies during working memory training can offer insights into what changes in the way that participants attempt to perform the tasks, and that this insight might help explain when transfer effects do and do not occur following training.

Despite these caveats, we gain confidence in the analyses of reported strategies from the observation of systematic and interpretable changes in reported strategies across conditions and across experiments. In addition, as discussed, the strategy analyses revealed important insights that have theoretical implications that we have discussed.

An interesting point from our results is the lack of participants' reports of a strategy that could be related to refreshing in Experiment 1 and 2 (that used an open-ended questionnaire). Refreshing is a mechanism whose existence is postulated by two of the three models discussed here (Barrouillet & Camos, 2021; Cowan, Morey & Naveh-Benjamin, 2021), and by which attention is shifted back on memory traces in working memory with the aim of reactivating them and avoiding their loss. There are at least two explanations to this lack of reports.

A first explanation is the potential difficulty of verbalizing such a mechanism. Merely saying something like “I just thought of the letters” might seem trivial to the participants. In support of this account, Morison et al. (2016) did observe reports of a strategy that could relate to refreshing: the “Concentrate” strategy (“I simply concentrated on the words”). However, these authors used a questionnaire listing 10 strategies including the one we just mentioned. We did not include such a strategy in the questionnaire for our Experiment 3 since it was built on the verbal reports of the participants in our Experiments 1 and 2. However, future research focusing more on Refreshing may benefit from adding the “concentrate” strategy to their questionnaires.

A second account of the lack of observed reports corresponding to the Refreshing mechanism could be that this mechanism is automatized to a certain level. The level of automatization of a process is generally defined through a certain number of features (Moors & De Houwer, 2006). Among these features, automatic processes are thought to be largely unconscious. If the mechanism of Refreshing has this feature, one should assume that participants are not able to report its use. In other words, during a dual-task condition participants might choose to pay more attention to the memoranda or to the processing task, but would not be aware of the precise way in which attention would shift rapidly back and forth between the two tasks. They would therefore be able to report their prioritization of the tasks (e.g., through reduction strategies), but not the precise amount of refreshing they did. In other words, refreshing might not be deliberate (which is another feature of automatic processes) and might not be conscious. This is exactly how “swift refreshing” has been described in the literature before (Camos et al., 2018). Nonetheless, the question of the automaticity of refreshing remains to be explored.

One other limitation of our study is that we have chosen to focus on only three models of working memory. These are arguably three of the most established models, although there

are others (e.g. Anderson, Bothell, Byrne, Douglass, Lebiere & Quin, 2004; Engle, 2018; Oberauer, 2009; Oberauer, Farrell, Jarrold & Lewandowsky, 2016; Unsworth & Engle, 2007; Unsworth & Spillers, 2010b; see Cowan, 2017 and Logie & al., 2021a for reviews). However, our primary goal in the studies reported here and in related papers (Doherty et al., 2019; Rhodes et al., 2019) was to explore the approach of three groups who have developed different models of working memory collectively designing and running experiments across labs to test different predictions on a common paradigm. We would argue that this relatively rare approach to experimental cognitive psychology appears to have generated some novel insights that are unlikely to have arisen from any individual lab working in isolation when using paradigms that are typical of their individual theoretical framework.

Conclusion

To conclude, our results showed that participants are able to adapt their strategies for memory and processing in verbal WM tasks. This reported adaptation appears to be systematic and sensitive to concurrent cognitive demands as well as to concurrent articulation. Other factors such as the modality of presentation of memory items can also impact on reported strategy choice. The exploration of strategies has helped interpret data patterns that were not predicted by each of the three models of working memory that we considered, and has pointed to ways in which there is potential for important advances in the understanding of dual task performance in working memory through theoretical integration rather than perpetuating theoretical adversity.

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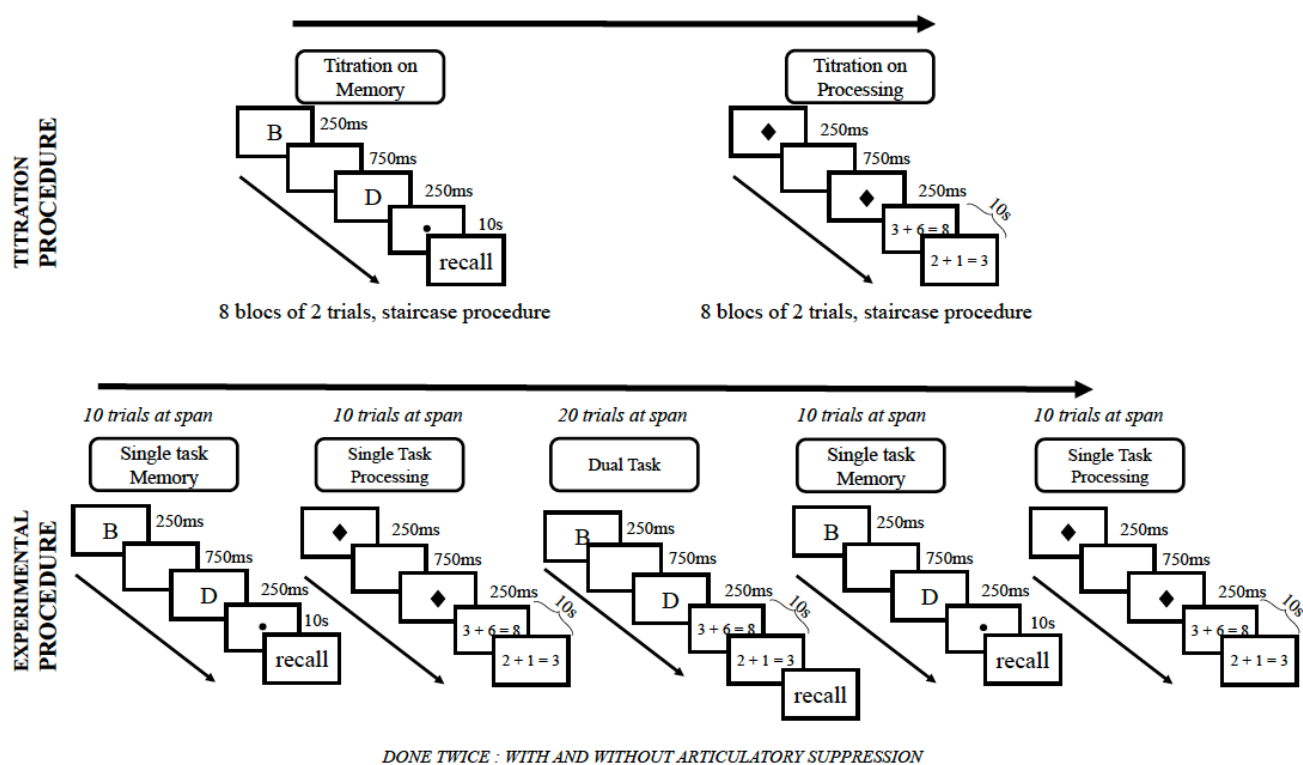


Figure 1: General procedure of Experiment 1.

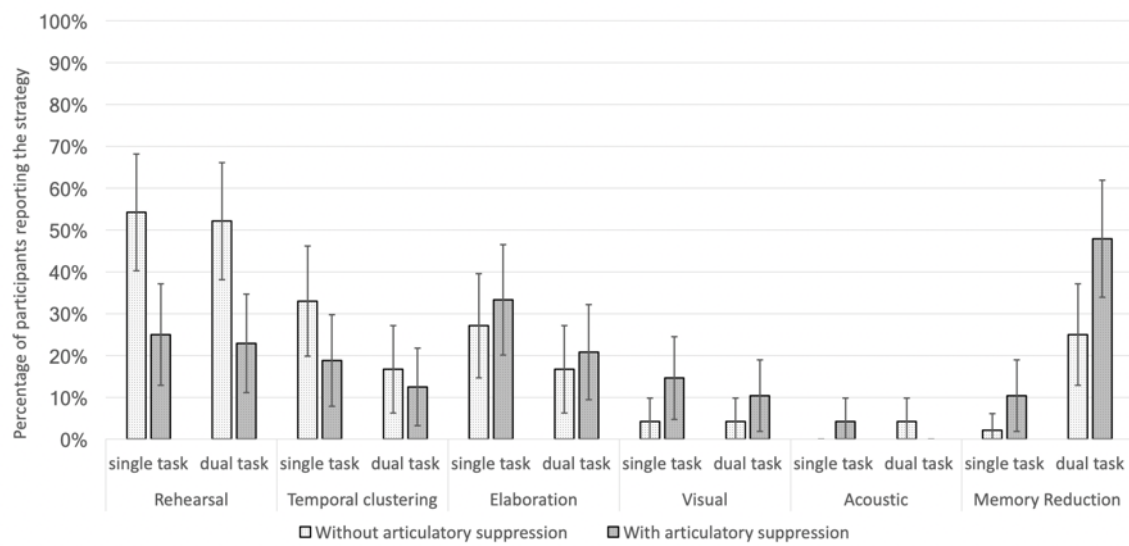


Figure 2: Percentages of participants reporting each memory strategy in each condition of Experiment 1 (with visually presented letters). Error bars represent confidence intervals at 95%.

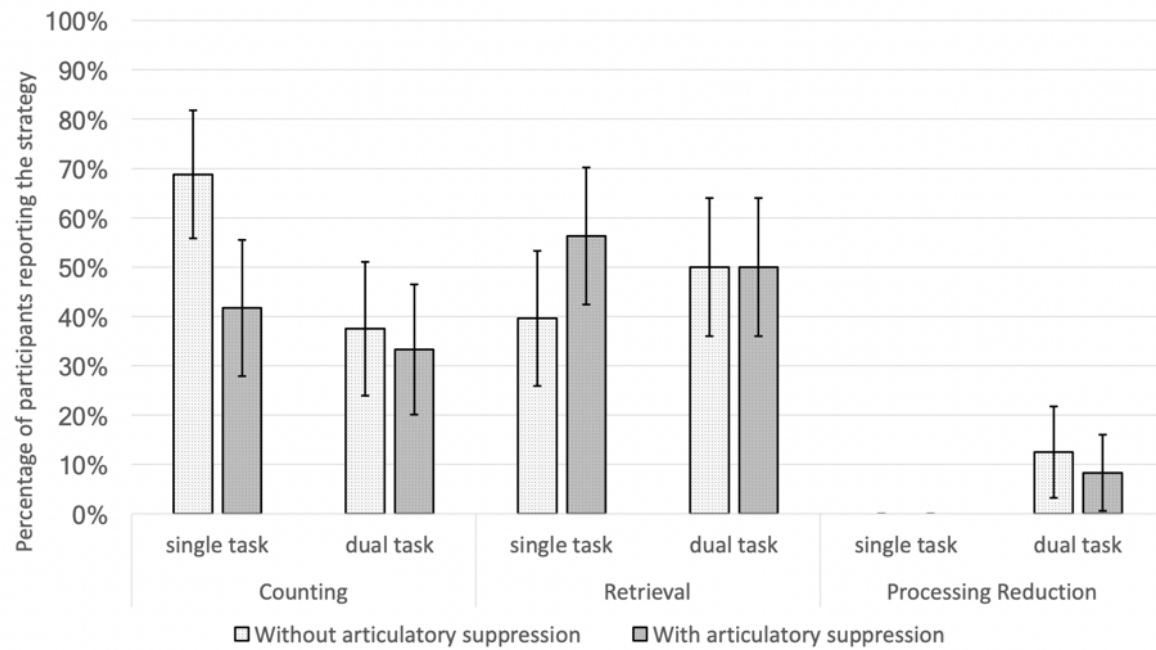


Figure 3: Percentages of participants reporting each processing strategy in each condition of Experiment 1 (with visually presented letters). Error bars represent confidence intervals at 95%.

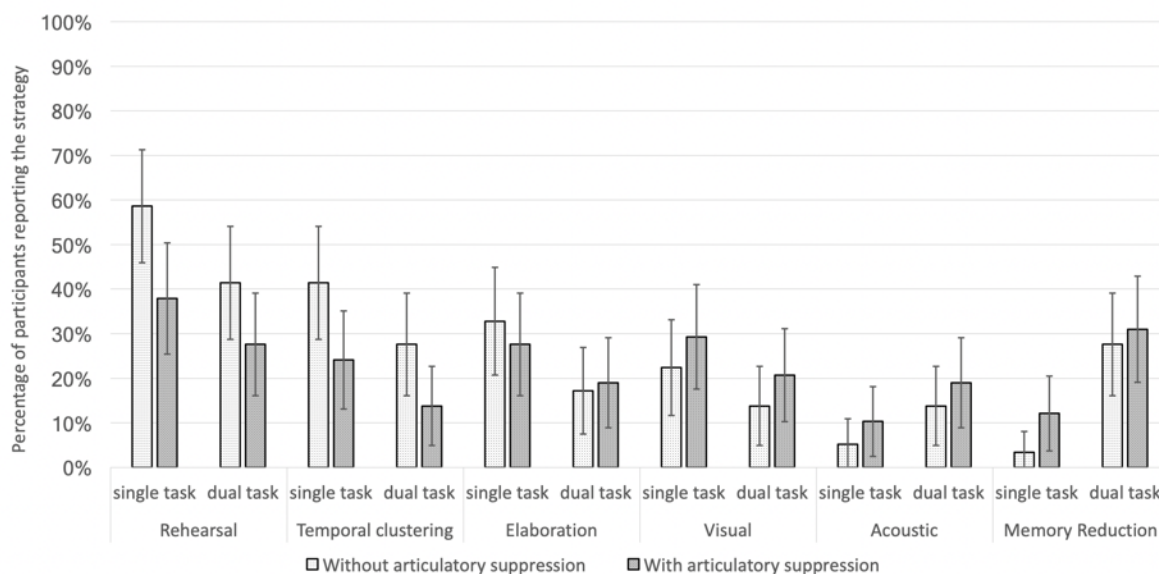


Figure 4: Percentages of participants reporting each memory strategy in each condition of Experiment 2 (with auditory presented letters). Error bars represent confidence intervals at 95%.

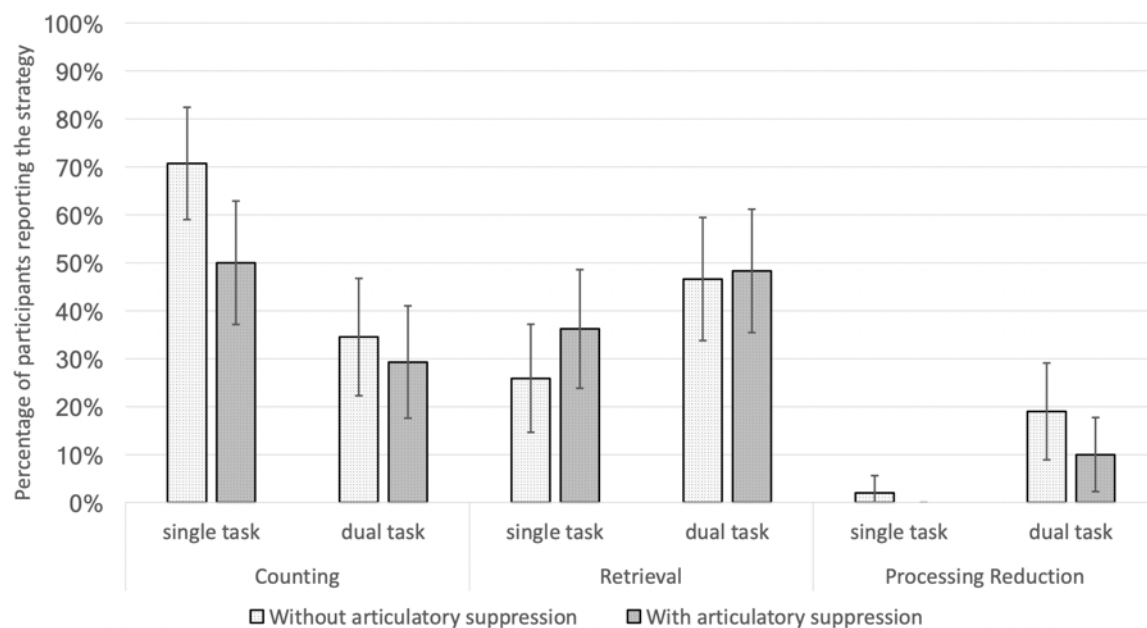


Figure 5: Percentages of participants reporting each processing strategy in each condition of Experiment 2 (with auditory presented letters). Error bars represent confidence intervals at 95%.

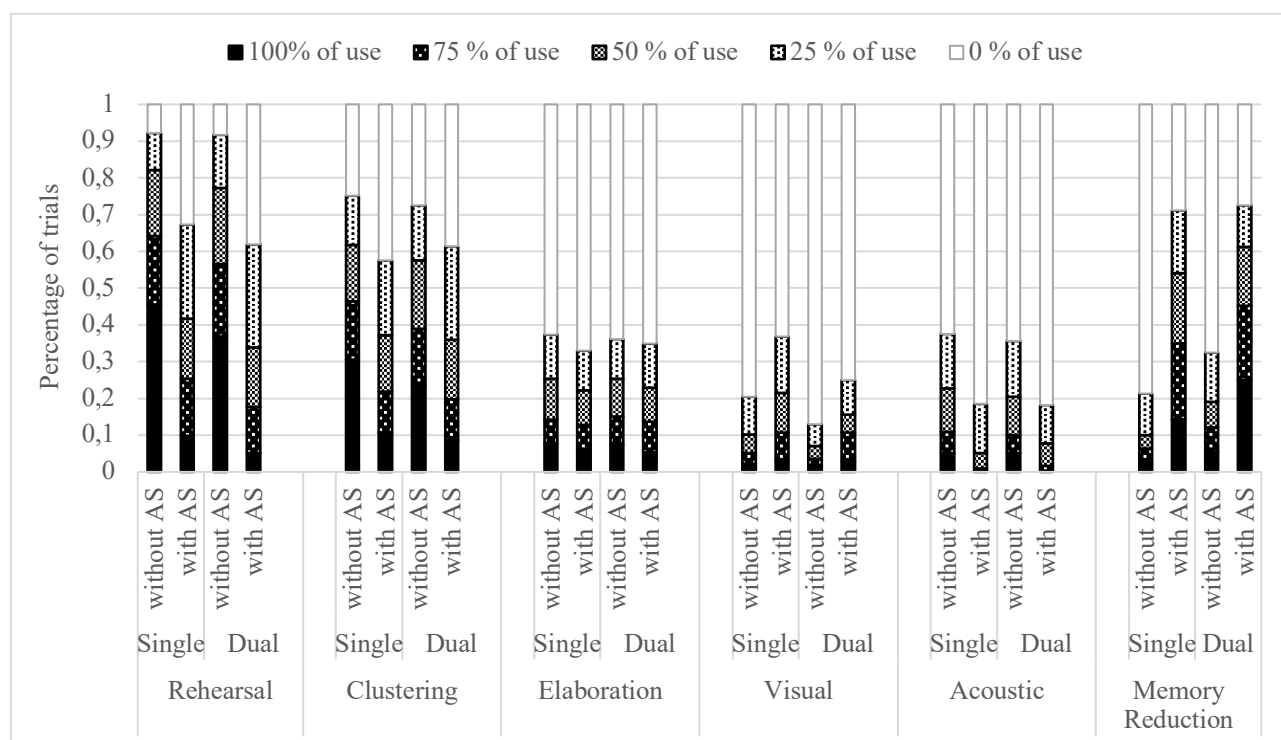


Figure 6: Rating for each memory strategy in each condition of Experiment 3 (with a trial-by-trial assessment). Participants were asked to which extent they used each strategy in the last trial and answered on a 5 point-Likert scale going from 0% to 100%.

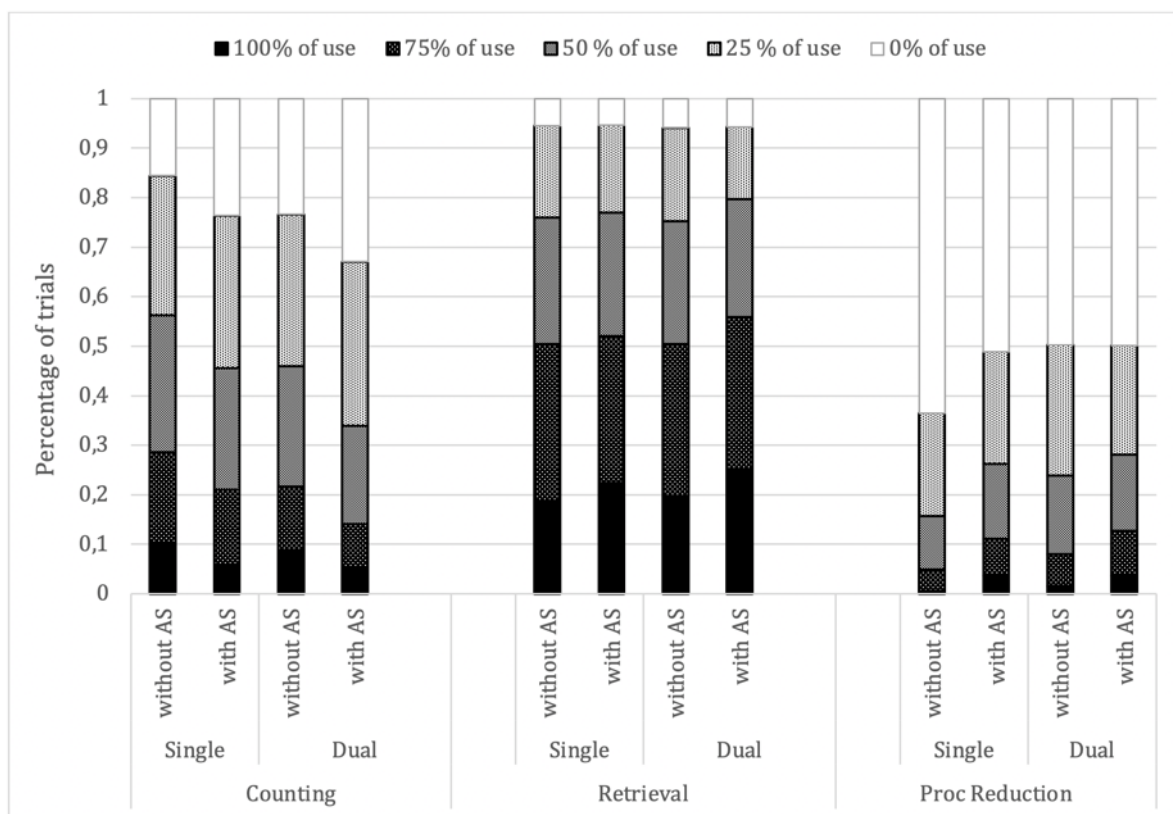


Figure 7: Rating for each processing strategy in each condition of Experiment 3 (with a trial-by-trial assessment). Participants were asked to which extent they used each strategy in the last trial and answered on a 5 point-Likert scale going from 0% to 100%.

Table 1. Open-ended questions at the end of each experiment.

Questions	Verbatim
Q1	How did you remember the series of letters when the letters were presented alone, without any other task at the same time?
Q2	How did you remember the letters when you had also to say 'ba-ba-ba'?
Q3	How did you remember the letters when you also had to verify the sums?
Q4	How did you remember the letters when you had to say 'ba-ba-ba' and verify the sums at the same time?
Q5	How did you verify the sums alone?
Q6	How did you verify the sums when you had also to say 'ba-ba-ba'?
Q7	How did you verify the sums when you also had to remember the letters?
Q8	How did you verify the sums when you had to say 'ba-ba-ba' and remember the letters at the same time?

Table 2. Classification of the memory strategies.

Name	Description	Example of participants' responses
Rehearsal	Repeating letters successively as in a loop	"repeating the letters mentally"
Temporal Clustering	Grouping letters by 2, 3 or 4	"I would try to remember them in groups of twos or threes"
Elaboration and Chaining	Associating letters with words or acronyms.	"looked for common acronyms or initials within the pattern to help me remember"
Visual	Memorizing visually the letters (sometimes by using the keyboard)	"I tried to visualize them on the screen"
Acoustic	Memorizing the sound of the letters and focusing on the sound itself	"I tried to recall the sound of the letter sequence"
Memory Reduction	Reducing the memory load by prioritizing addition verifications or by dropping some or all letters	"just focused on some letters, rarely tried to remember all"
Others	Other strategies	"I tried to associate a letter with a single finger"

Table 3: Effects of the task condition and the articulatory suppression (AS) on the use of each memory strategies in Experiments 1 and 2.

		Experiment 1		Experiment 2	
		Wald Z	<i>p</i>	Wald Z	<i>p</i>
Task Condition	Rehearsal	ns	ns	7.35	<.01
	Clustering	8.68	<.01	8.53	<.01
	Elaboration	4.76	.03	6.19	.01
	Visual	ns	ns	ns	ns
	Acoustic	NA	NA	3.90	.05
	Memory	30.19	<.001	17.87	<.001
	Reduction				
Articulatory Suppression	Rehearsal	17.33	<.001	10.73	<.001
	Clustering	4.69	.03	13.23	<.001
	Elaboration	ns	ns	ns	ns
	Visual	6.95	<.01	ns	ns
	Acoustic	NA	NA	ns	ns
	Memory	7.64	<.01	ns	ns
	Reduction				

Note: NA indicated that the number of participants reporting this strategy was too low to perform analysis, ns for non-significant effects. Interactions between Task condition and AS were not reported, because they were never significant.

Table 4. Classification of the strategies used for the addition verification task.

Name	Description	Example of participants' responses
Counting	Verifying additions through a step-by-step calculation	“try and solve the first two numbers mentally first”
Retrieval	Verifying additions “intuitively” or knowing them "by heart"	“answered those I remembered by heart”
Processing Reduction	Reducing the processing load by prioritizing memory or by giving up some or all addition verifications	“I tend to remember the letters and not focusing on the sums”
Others	Other strategies	“based on even and odd numbers”

Table 5: Effects of the task condition and the articulatory suppression on the use of each processing strategies in Experiments 1 and 2.

		Experiment 1		Experiment 2	
		Wald Z	<i>p</i>	Wald Z	<i>p</i>
Task Condition	Counting	11.75	<.01	21.35	<.001
	Retrieval	ns	ns	10.17	<.001
	Processing	NA	NA	NA	NA
	Reduction				
Articulatory Suppression	Counting	13.87	<.001	13.13	<.001
	Retrieval	4.26	.04	ns	ns
	Processing	NA	NA	NA	NA
	Reduction				
Interaction	Counting	8.91	<.01	4.09	.04
	Retrieval	5.92	.02	Add Mod	Add Mod
	Processing	NA	NA	NA	NA
	Reduction				

Note: NA indicated that the number of participants reporting this strategy was too low to perform analysis, ns for non-significant effects. Add Mod specified that an additive model was preferred; the interaction term was therefore not computed.

Table 6: Spearman's correlations between the reported memory strategies and of these strategies with the memory performance in Experiment 3.

Variable	Rehearsal	Clustering	Elaboration	Acoustic	Visual	Memory Reduction
Rehearsal	—					
Clustering	0.282 ***	—				
Elaboration	-0.185***	0.035	—			
Acoustic	0.216 ***	0.131 ***	-0.004	—		
Visual	-0.070***	-0.039 *	-0.080 ***	0.045 *	—	
Memory Reduction	-0.269***	-0.171 ***	-0.194 ***	0.107***	0.083***	—
Memory Performance	0.367 ***	0.263 ***	0.205 ***	0.151***	0.115***	-0.462 ***

Table 7: Spearman's correlations between the reported processing strategies and of these strategies with the processing performance in Experiment 3.

Variable	Counting	Retrieval	Processing Reduction
Counting	—		
Retrieval	-0.443***	—	
Processing Reduction	-0.183***	-0.178***	—
Processing Performance	0.063***	0.120***	-0.225***

ANNEX A: Verbatim of the questionnaire in experiment 3

Text displayed before the first memory single-task:

“In the following sections, at the end of each trial you will be asked about the strategies that you used to memorize the letters. More specifically, you will be asked about the following strategies:

REHEARSAL, that refers to the repeating of the letters out loud or silently

TEMPORAL CLUSTERING, that refers to the grouping in groups of 2 or 3 letters, without any reference to prior knowledge, for example grouping XQBPWM into XQB and PWM

ELABORATION, that refers to the linking of the letters with previous knowledge. For example, for the letters NHSCLM, one may remember the acronym NHS and/or the word CaLM

ACOUSTIC STRATEGY, that refers to the focusing on the sound of the letters

VISUAL STRATEGY, that refers to the focusing on the visual appearance of the letters (their shape)

MEMORY REDUCTION, that refers to trying to remember only some letters (for example the first 2 or 3 letters) and to not try to remember all of them.

After each trial you will be asked to rate the extent to which you used particular strategies on that trial. For each strategy you will provide a rating of 0%, 25%, 50%, 75%, or 100%. The ratings you give **do not** need to sum up to 100% and should be an estimate of the extent to which you used the strategy in question on that trial.

For example, if you repeated either aloud or in your head the first three letters in a sequence of six you could respond 50% to the rehearsal strategy; or if you did not try to remember the last two letters in a sequence of seven you could respond 25% to the memory reduction strategy. The ratings you give do not have to precisely match the degree to which you used a strategy but should be a rough estimate. Go with your quick intuition or feeling regarding each rating rather than taking a long time to be exact on each one.”

Text displayed before the first processing single-task:

“In the following sections, at the end of each trial you will be asked about the strategies that you used to verify the additions. More specifically, you will be asked about the following strategies:

COUNTING, that refers to the fact to first compute the sum, and then to compare the result with the displayed answer

RETRIEVAL, that refers to relying on intuition or to the fact to just know the additions by heart

PROCESSING REDUCTION, that refers to trying to verify only some additions and/or to guess

After each trial you will be asked to rate the extent to which you used particular strategies on that trial. For each strategy you will provide a rating of 0%, 25%, 50%, 75%, or 100%. The ratings you give **do not** need to sum up to 100% and should be an estimate of the extent to which you used the strategy in question on that trial.

For example, if you computed the sums for 3 additions in a sequence of six you could respond 50% to the counting strategy; or if you did not try to answer the last two additions in a sequence of seven you could respond 25% to the processing reduction strategy. The ratings you give do not have to precisely match the degree to which you used a strategy but should be a rough estimate. Go with your quick intuition or feeling regarding each rating rather than taking a long time to be exact on each one. “

Text displayed before the first dual-task:

At the end of each trial, you will be asked about the strategies that you used to remember the letters AND the strategies that you used to verify the additions

Likert Scales for the memory strategies:

Please answer the following questions as spontaneously and honestly as possible. When you have answered all the questions, press CONTINUE.

In the last trial...

...to which extent did you repeat the letters?

...to which extent did you group the letters? For example, to remember TGPLKM did you group the letters in two groups: TGP and LKM, or perhaps in three groups TG PL KM?

...to which extent did you associate letters with words, known acronyms or nouns to help you remember? For example, for the letters NHSCLM, did you remember the acronym NHS and/or the word CaLM?

...to which extent did you remember how the letters sounded?

...to which extent did you picture the letters (their shape) in your head? For example, for the letters TLGRBS, did you mentally picture the shape of each letter?"

...to which extent did you try to remember only some letters (for example only the first 2 or 3 letters), and did not try to remember all of them?"

Likert Scales for the processing strategies:

Please answer the following questions as spontaneously and honestly as possible. When you have answered all the questions, press CONTINUE.

In the last trial...

...to which extent did you try to compute the sum and then to compare it with the displayed answer?

...to which extent did you answer the additions intuitively or by heart?

...to which extent did you try to solve only some additions and/or did you try to guess?