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High cognitive load abolishes auditory distraction in short-term memory: Implications for working memory-based attentional control and an alternative task-engagement account

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ABSTRACT

The current study critically examined a common theoretical view in which there exists a distinct working memory (WM) system that not only temporarily stores information but also acts as an attentional controller (the *Working Memory—Attentional Control* account). A central prediction of this account is that an increase in cognitive load should take up some of the system's capacity for attentional control and thereby render short-term storage more vulnerable to distraction by task-irrelevant stimuli. The present results directly contradict this prediction: The requirement to engage in an additional concurrent articulation task during short-term serial recall abolished not only the classical changing-state irrelevant sound effect but also attentional capture by an auditory deviant (Experiments 1a and 1b). The deviation effect was also abolished under concurrent articulation in a task involving little if any serial rehearsal (the missing-item task), as indicated independently by the fact this task was immune to a detrimental main effect of concurrent articulation and to a changing-state effect (Experiment 2). We argue that concurrent articulation not only specifically impedes serial rehearsal in the context of serial recall but also imposes a nonspecific cognitive load (regardless of task). However, rather than drain capacity from a distinct WM system, such increased load boosts task engagement which in turn shields performance against forms of distraction that are due to task-disengagement. The task-engagement view may also provide an alternative account of numerous findings that are typically cited in support of the Working Memory—Attentional Control view.

Introduction

It is commonly assumed that there exists a limited-capacity working memory (WM) system devoted to the concurrent short-term storage and processing of information required for complex cognition (e.g., Baddeley, 2007; Elliott & Cowan, 2005; Engle, 2002; Oberauer, 2019). As part of the continuing refinement of this view, a great deal of research has centred on explicating the link between WM and attention, with one commonly held idea being that the latter is a function of the former, e.g., "working memory plays a key role in maintaining processing priorities, so that target and distractor-related information remains clearly separated in processing, and behavior can be successfully directed toward task-relevant information" (De Fockert, 2013, p. 3; see also Dalton et al., 2009; De Fockert, 2013; Elliott & Cowan, 2005; Kane et al., 2001; Lavie et al., 2004; Unsworth & Engle, 2007; for a review, see Oberauer, 2019). Indeed, in this view, individual differences in WM capacity are thought to be underpinned specifically by differences in the attentional control component of WM, in particular where "there is value in maintaining some task information in the face of distraction and interference" or "in suppressing or inhibiting information irrelevant to the task" (Engle et al., 1999, p. 104).

A central prediction of this *Working Memory-Attentional Control (WM-AC)* account[1] is that an experimental increase in (non-perceptual) processing load (also sometimes called 'working memory load' or 'cognitive

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[1] Others have referred to this view as the *fusion account* (Oberauer, 2019) but we thought a more specific term that includes explicit reference to the two fused constructs might be useful.

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load', e.g., Lavie et al., 2004), such as performing a secondary task, should usurp WM capacity, leaving performance more vulnerable to interference from task-irrelevant stimuli. And indeed, numerous studies appear to confirm this prediction (e.g., Dalton et al., 2009; De Fockert et al., 2001; Kelley & Lavie, 2011; Lavie et al., 2004; Muller-Gass & Schröger, 2007). The present study was motivated by the observation that the basic premise of the WM-AC account—that short-term storage and attentional control are functions of the same limited-capacity WM system—seems to provide a straightforward explanation for why the short-term storage component of WM—as measured by serial recall—is itself acutely sensitive to distraction, particularly from irrelevant auditory stimuli (e.g., Beaman, 2004; Colle & Welsh, 1976; Elliott, 2002; Hughes et al., 2007; Jones & Macken, 1993; Neath, 2000; Salamé & Baddeley, 1982): As the serial recall task itself is, by design, highly taxing of WM, this leaves relatively little capacity for filtering out irrelevant stimuli such as auditory distractors. In the present study, we test the prediction of WM-AC that introducing an additional cognitive load during a short-term memory task (concurrent articulation) should lead to yet greater levels of auditory distraction. We will contrast this prediction of the WM-AC account with a task-engagement account that makes the opposite prediction: that an increase in load can boost task-engagement and shield against certain forms of distraction (Hughes et al., 2013).

Auditory distraction in short-term memory and the WM-AC account

There exists a large body of research indicating that the core function of WM—short-term storage—is highly vulnerable to distraction by task-irrelevant material, particularly sound (e.g., Colle & Welsh, 1976; Hughes & Jones, 2001, 2005; Jones & Macken, 1993; Salamé & Baddeley, 1982). Specifically, short-term recall of the order of around six to eight verbal items (e.g., digits) presented one by one on a screen is impaired markedly by the presence of a to-be-ignored changing-state sequence of sounds such as *"B, Q, J, G…"* (or a succession of tones changing in frequency) compared to a repeated sound such as *"B, B, B, B…"* (or a repeating tone) (e.g., Bell et al., 2019; Divin et al., 2001; Hughes et al., 2007; Jones & Macken, 1993; Jones et al., 1992). A broad explanation of such distraction would seem to follow naturally from the WM-AC account: The focal task itself draws heavily upon WM capacity as it requires the short-term storage of a supra-span list of items and hence there is relatively little capacity for the attentional control function to prevent the sound from intruding into WM. One line of evidence cited as support for the WM-AC account generally is that, across many task-settings, individuals with high WM capacity—as measured by WM span tasks such as operation span (Turner & Engle, 1989)—are better able to resist distraction (Conway et al., 2001; De Fockert, 2013; Sörqvist, 2010a,b). A number of research groups have therefore examined whether such individuals are also less susceptible to changing-state irrelevant sound. Contrary to the prediction of WM-AC, none of them found such a correlation (e.g., Beaman, 2004; Elliott & Briganti, 2012; Georgi et al., 2023; Hughes et al., 2013; Körner et al., 2017; Röer et al., 2015; Sörqvist, 2010b; Sörqvist et al., 2013).

The second major line of evidence taken as support for the WM-AC account—which will form the focus of the present study—is that increasing 'working memory load' or cognitive load directly and experimentally (as opposed to indirectly and pseudoexperimentally via individual differences in WM capacity) increases distraction from task-irrelevant stimuli (for a review, see De Fockert, 2013). For example, in visual choice reaction time studies, having to concurrently rehearse even a single digit, or merely having to co-ordinate two tasks regardless of the load imposed by either task alone (i.e., the *cost of concurrence,* Navon & Gopher, 1979; Logan & Gordon, 2001), increases distraction. More specifically, increased cognitive load has been found to exacerbate distraction from flankers in a concurrently performed speeded target-identification task (Lavie et al., 2004), distraction from an incongruent famous face while attempting to categorize (by occupation) a famous name (e.g., De Fockert et al., 2001; Pecchinenda & Heil, 2007), distraction from task-irrelevant singletons during visual singleton search (Lavie & De Fockert, 2005), and from sounds that are incongruent with the response required to another, concurrently-presented, sound (Dalton et al., 2009; see also Muller-Gass & Schröger, 2007).

It would appear to follow, then, that in the context of an already taxing verbal serial recall task, having to take on a secondary cognitive load, such as concurrent articulation of an irrelevant verbal sequence (cf. Gupta & MacWhinney, 1995; Murray, 1968; Neath, 2000), should leave the WM system even more vulnerable to distraction from extraneous input such as irrelevant sound. However, whilst concurrent articulation does affect the changing-state irrelevant sound effect, it does so in the opposite direction to that predicted by WM-AC: it abolishes it (AuBuchon et al., 2020; Beaman & Jones, 1997; Divin et al., 2001; Hughes & Marsh, 2017; Jones et al., 2004; Salamé & Baddeley, 1982).

The attenuating impact of concurrent articulation on the changing-state irrelevant sound effect, as well as the absence of an association between the changing-state effect and WM capacity, is consistent with an interference-by-process account of this form of distraction: changing-state disruption results from specific interference between the obligatory processing of the order of a succession of changing sounds—such order cues being minimal or non-existent with a steady-state sound—and the volitional articulatory serial rehearsal of the to-be-remembered items (e.g., AuBuchon et al., 2020; Beaman & Jones, 1998; Hughes & Jones, 2005; Jones & Macken, 1993). In this view, the changing-state effect is attenuated under concurrent articulation because concurrent articulation blocks or impedes the same specific process (articulatory serial rehearsal) that is vulnerable to the changing-state effect (Jones et al., 2004). The positive correlation in the context of serial recall between susceptibility to the changing-state effect and to concurrent articulation further supports the view that the two effects share a common locus (Neath et al., 2003). Of particular interest in the present context, the changing-state effect does not, however, correlate with individual differences in WM capacity because, on the interference-by-process account, the changing-state effect is not due to attentional diversion. It would thus not be expected to be related to the attentional control processes assumed to underlie that capacity (Engle, 2002; Macken et al., 2009).

The elimination of the changing-state effect by concurrent articulation and the lack of a correlation between the changing-state effect and WM capacity appear to be at odds with the WM-AC account. However, this conclusion may be premature: proponents of the WM-AC account might claim that distraction from changing-state sound is something of an anomaly, where the elimination of this form of distraction by concurrent articulation, for example, occurs because both variables have a highly selective effect on articulatory serial rehearsal. That is, WM-AC might effectively adopt the interference-by-process account of the changing-state effect (see, e.g., Elliott & Cowan, 2005). In light of this, in the present study we capitalize for the first time on a more general, attentional, form of auditory distraction to which short-term memory is also susceptible to provide a more definitive test of the WM-AC account.

Distraction by an auditory deviant

An unexpected single deviant sound embedded within an irrelevant sound-sequence presented during verbal serial recall—e.g., one token spoken in a different voice from the remaining tokens—impairs performance over and above any changing-state effect (e.g., Hughes et al., 2005, 2007, 2013; Röer et al., 2015; Vachon et al., 2020). There is good evidence that this *deviation effect* is functionally distinct from the changing-state effect (e.g., Alikadic & Röer, 2022; Hughes et al., 2007, 2013; Marois et al., 2019; Sörqvist, 2010b; Vachon et al., 2012). Of particular importance in relation to the rationale for the present study is that the deviation effect, unlike the changing-state effect, is not specific to tasks that rely on or tend to involve serial rehearsal. For example, if the task calls only for the recall of the items in a list without recourse to their order—hence stripping the task of a need for serial rehearsal—the deviation effect is still produced (whereas the changing-state effect is not, unless participants happen to still adopt a serial rehearsal strategy; Elliott et al., 2016; Hughes & Marsh, 2020; Hughes et al., 2007; Jones & Macken, 1993; see also Beaman & Jones, 1997; MacDermid et al., 2023; Marsh et al., 2017). Indeed, distraction by an auditory deviant has been observed across a range of tasks that do not contain an obvious serial rehearsal component, including the speeded classification of individual visual stimuli (e.g., Elliott & Cowan, 2001; Parmentier, 2008; SanMiguel et al., 2008; Schröger & Wolff, 1998). As such, any attenuating effect of concurrent articulation on the deviation effect could not be readily attributed to an effect of concurrent articulation on serial rehearsal (this possibility is nonetheless tested directly in Experiment 2). Indeed, there is universal agreement, including amongst proponents of the WM-AC framework, that the deviation effect is a relatively task- or process-insensitive form of distraction resulting from *attentional diversion* or *attentional capture*; a disengagement of attention from the prevailing activity (e.g., Hughes et al., 2005, 2007, 2013; Elliott et al., 2016; Kattner, 2025; Marois et al., 2019; Saults & Cowan, 2007; Labonté et al., 2021; Röer et al., 2015). Indeed, part of the support for this view comes from the fact that a number of studies have shown that susceptibility to the deviation effect, unlike the changing-state effect, negatively correlates with WM capacity (Hughes et al., 2013; Labonté et al., 2021; Marsh et al., 2017; Sörqvist, 2010b; see also Sörqvist et al., 2013; but also Körner et al., 2017; Röer et al., 2015). As such, the deviation effect provides an apposite tool to test WM-AC's prediction that experimentally increasing cognitive load should exacerbate the disruption of short-term memory.

There is already some evidence on the interplay of the deviation effect and load during serial recall that seems to contradict the predictions of the WM-AC account: Increasing task encoding-load by degrading the visibility of the to-be-recalled items eliminates the deviation effect as does requiring the recall of the colours in which a series of Stroop colour-words appear (high load) compared to recalling the colour-words themselves (low load) (Hughes & Marsh, 2019) or requiring the recall of the local dimension of each of a series of Navon letters (high load) compared to their global dimension (low load; Marsh et al., 2020; Navon, 1977). At first glance, these results seem inconsistent with the WM-AC account's prediction that increased load should increase distraction. However, an alternative possible explanation is that the manipulations implemented in these studies were ones of *perceptual* load, which, according to some proponents of the WM-AC account, should be strongly distinguished conceptually from cognitive load: In this view, high perceptual load within a focal task leaves little or no capacity for perceptually processing task-irrelevant stimuli, hence their distracting effects are, in contrast to the effects of cognitive load, expected to be diminished, not exacerbated (e.g., De Fockert, 2013; Lavie, 1995, 2005).

A finding from outside the short-term recall setting that is also seemingly at odds with WM-AC, however, and which cannot so readily be explained away as a perceptual load effect comes from a study by Berti and Schröger (2003). They found that reaction time to make a discrimination judgment on the duration of each of a series of tones (long vs. short) was impaired to a lesser, not greater, degree by a rare deviation in the frequency of the tones when load was increased by requiring the judgment to be made on the tone presented on trial $n-1$ rather than trial n (see also SanMiguel et al., 2008, 2010; Sörqvist et al., 2012; Parmentier et al., 2008). This n-back manipulation is clearly not one of perceptual load and indeed has long been considered a classic method for varying "WM load" (Kirchner, 1958). However, it arguably involves a manipulation of load within the context of a single task whereas the vast majority of studies that have found that increased load exacerbates distraction have increased load using a secondary task (e.g., Lavie et al., 2004). Whilst it is unclear why, on the WM-AC account, this should matter, it may nonetheless be a key methodological difference.

Present study

In the present experiments, we examine for the first time the effect of concurrent (whispered) articulation on the auditory deviation effect in the context of verbal serial recall (Experiment 1) and also in a missing-item task (Experiment 2). Given that concurrent articulation does not entail the encoding of new perceptual information, it could not plausibly be conceptualized as an increase in perceptual load (cf. Lavie, 2005). It also constitutes a manipulation of load that is clearly separate from the task in which performance is measured (Lavie et al., 2004; cf. Berti & Schröger, 2003). Thus, the WM-AC account predicts that concurrent articulation should exacerbate the deviation effect because, as a secondary cognitive load, it should usurp WM capacity otherwise used to inhibit distraction. As noted, given that a deviant does not specifically interfere with serial rehearsal, the WM-AC account could not in this case readily appeal to the notion that concurrent articulation might attenuate the deviation effect by impeding serial rehearsal (see also Experiment 2).

We contrast the predictions of WM-AC with those based on a *task-engagement account* that we developed in earlier work to explain the reduction of the deviation effect under high encoding load (e.g., Hughes et al., 2013). At the core of this account is the notion that an increase in load can trigger a compensatory boost in active task-engagement designed to counteract the otherwise damaging effect of that increased load on task performance, an idea that has been most prominent in the human factors literature (cf. Eggemeier et al., 1983; Hockey, 1997; O'Donnell & Eggemeier, 1986; Wickens, 2008). We suggested that such an increase in task-engagement, in turn, can shield against effects that are due to momentary task-disengagement such as attentional capture by a deviant (Hughes, 2014; Hughes et al., 2013; Hughes & Marsh, 2019; Marsh et al., 2020; for similar views, see, e.g., Berti & Schröger, 2003; Buetti & Lleras, 2016; Kim et al., 2005; SanMiguel et al., 2010). More specifically, in this view, increased task-engagement involves heightened activation of a task-set comprising, for example, representations of the task goal, the rules and/or strategies required to achieve it, expectations about what task-relevant stimuli might plausibly occur in a given setting (stimulus set), and stimulus–response mappings (e.g., Allport et al., 1994; Desimone & Duncan, 1995; Marsh et al., 2020). Such cognitive adjustments are typically assumed to be supported by concomitant changes in motivation-based arousal that enable sustained task-focused processing under increased demands (e.g., Eggemeier et al., 1983; Hockey, 1997; Kahneman, 1973).

Importantly, this account does not predict different outcomes as a function of type of load (e.g., 'encoding', 'perceptual', 'cognitive/working memory'): an increase in load pertaining to any aspect of the task-setting in which the participant must actively engage—including any secondary-task activity or the mere act of co-ordinating two (or more) tasks—could in principle elevate the overall level of task-engagement and attenuate distraction by task-irrelevant stimuli. As such, we predicted that the requirement for concurrent articulation, just like an increase in encoding load, should attenuate or eliminate the impact of an auditory deviant. We also expected to replicate the finding that the changing-state effect is attenuated by concurrent articulation, due in this case to the specific action of concurrent articulation on articulatory serial rehearsal (e.g., Hanley, 1997; Jones et al., 2004; Salamé & Baddeley, 1982).

Experiment 1a

In Experiment 1a, participants were asked to recall lists of eight visually-presented digits in serial order under conditions of to-be-ignored steady-state speech tokens or changing-state speech tokens. Within each of these conditions, on a minority of trials, an unexpected deviation in the voice conveying the tokens occurred midway through the auditory sequence (cf. Hughes et al., 2007; Hughes et al., 2013). These four auditory conditions—(1) steady-state/no-deviant; (2) steady-state/with-deviant; (3) changing-state/no-deviant; and (4) changing-state/with-deviant—were undertaken either with or without concurrent articulation.

To reiterate the predictions of the two opposing theoretical views, both the WM-AC account and the task-engagement account predict poorer recall in the presence of concurrent articulation and in the presence of a deviant. However, the WM-AC account predicts that the additional requirement to engage in concurrent articulation should exacerbate the deviation effect because this additional cognitive load is expected to drain WM capacity required to suppress distractors (e.g., Lavie et al., 2004). In contrast, the task-engagement account predicts that concurrent articulation should reduce or abolish the deviation effect because the increased cognitive load may be expected to induce a compensatory boost in task engagement, a side-effect of which is the suppression of distraction effects, such as the deviation effect, that are thought to result from task-disengagement (cf. Hughes et al., 2013).

Method

Sample size/power

Although the current experiment was the first to examine a possible interaction between concurrent articulation and the deviation effect, Hughes and Marsh (2017, Experiment 2) found that the effect of concurrent articulation on the disruptive impact of irrelevant sound (that did not contain a deviant) had an effect size of $\eta_p^2 = .15$. According to GPower (Faul et al., 2009) a sample size of 20 allows for the detection of an effect of this size or larger with 80% power (with alpha-level set at .05).

Participants

In the event, 24 participants were recruited from the campus community at Cardiff University who took part in return for a small honorarium. For both this experiment and Experiment 2, participants were required at sign-up to commit to two testing sessions. These sessions could not occur on the same day but had to take place within one week of one another in order for participants to receive course credit. All participants completed both sessions within the required one-week timeframe. All participants reported normal hearing and normal or corrected-to-normal vision. Ethical approval for the experiments reported in this article was granted by the ethics committee of the School of Psychology, Cardiff University (Experiment 1) or of the School of Psychology, University of Central Lancashire (Experiment 2). For all experiments, the privacy rights of the human subjects were observed and their informed consent obtained.

Apparatus & materials

Fig. 1 illustrates the main elements of the experiment. The to-be-remembered visually-presented lists comprised eight digits sampled pseudo-randomly without replacement from the set *1–8*. The lists were presented one digit at a time in the centre of a screen for 350 ms each, followed by a 450 ms inter-stimulus interval. There were no ascending or descending runs of two or more digits, there were no digits in successive trials sharing the same within-sequence position, and no sequences began with the digit ‘1′ or ended with the digit ‘8′.

For the irrelevant auditory sequences, two sets of spoken letters (*A, B, C, G, J, K, L, M, Q,* and *S*) were recorded, one set in a female voice and the other in a male voice. In each set, the letters were recorded in a monotone voice with a 16-bit resolution at a sampling rate of 22.05 kHz using *Sony Sound Forge 8.0* software (Sony Creative Software), and each was edited to a duration of 250 ms. Using these stimuli, four types of irrelevant auditory sequence were generated: (1) steady-state/no-deviant; (2) steady-state/with-deviant; (3) changing-state/no-deviant; and (4) changing-state/with-deviant.

The steady-state/no-deviant sequences were constructed by selecting a single female-spoken letter (chosen at random for each sequence) and presenting that letter ten times. The steady-state/with-deviant sequences were the same as the steady-state/no-deviant sequences except

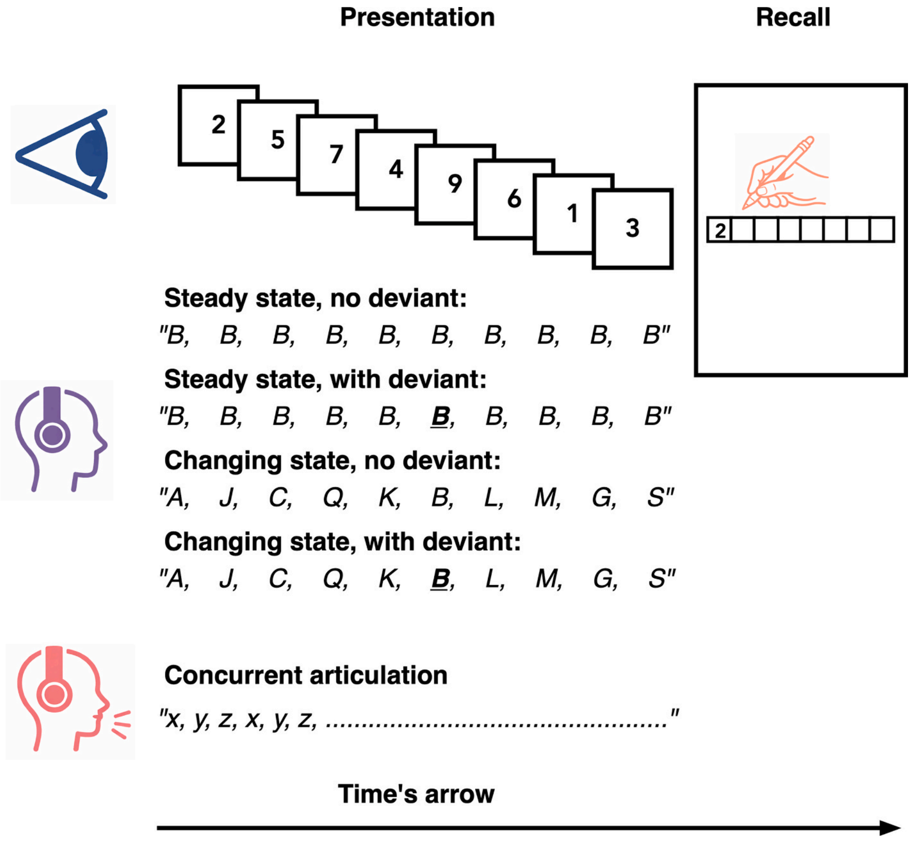

Fig. 1. Schematic illustration of the basic elements of the method of Experiment 1a. See Method of Experiment 1a for further details.

that the sixth token was a deviant: it was conveyed in a male rather than a female voice (note that the particular voice—male or female—conveying the deviant vs. non-deviant tokens has been shown not to make any difference; Hughes et al., 2013; Vachon et al., 2012). The changing-state/no-deviant sequences were constructed using all ten female-spoken letters presented in a different random order for each sequence. The changing-state/deviant sequences were the same except that the sixth letter was conveyed in a male rather than a female voice.

In all conditions, the first token of the irrelevant auditory sequence preceded the onset of the first to-be-remembered item by 150 ms with a 350 ms inter-stimulus interval between each spoken letter. Using these timings, the voice-deviant on with-deviant trials occurred 125 ms before the fifth to-be-remembered item (as in Hughes et al., 2007). The irrelevant auditory sequences were presented via headphones at a sound level of approximately 65 dB(A). The experiment was executed on a PC running a bespoke *E-prime 2.0* program that controlled stimulus presentation.

Design

The experiment employed a 2 (Concurrent articulation: with-concurrent articulation vs. no-concurrent articulation) × 2 (State: steady-state vs. changing-state) × 2 (Deviation: no-deviant vs. with-deviant) within-participant design. The concurrent articulation factor was blocked, with each block further sub-divided into a steady-state block (45 trials) and a changing-state block (45 trials) with no pause between (thus, there were 180 trials in total, 90 in the with-concurrent articulation block and 90 in the no-concurrent articulation block). The steady-state block consisted of 39 steady-state/no-deviant trials and 6 steady-state/with-deviant trials; likewise, the changing-state block consisted of 39 changing-state/no-deviant trials and 6 changing-state/with-deviant trials. The order of the concurrent articulation blocks as well as the order of the steady-state and changing-state blocks within each concurrent articulation block was fully counterbalanced across participants. To ensure that the particular to-be-remembered sequences and irrelevant auditory sequences were not systematically associated with a particular concurrent articulation condition, there were two sets of to-be-remembered and irrelevant auditory sequences rotated over the two concurrent articulation blocks. In one of these sets, the six with-deviant sequences in both the steady-state and changing-state blocks were presented on trials 5, 8, 18, 27, 35, and 41, whilst in the other they were presented on trials 10, 21, 24, 33, 38, and 45.

Procedure

Participants were tested individually in a sound-attenuated booth with the Experimenter present outside the booth in a control room. They were first given standardized instructions describing the serial recall task. They were also informed that the background sound was irrelevant to the recall task and that they should therefore do their best to ignore it. The participants were not informed that auditory voice-deviants would be presented on some of the trials. Following the final to-be-remembered item, participants were to recall the sequence in forward serial order by writing each item, from left to right, in one of eight locations on a response sheet, where each location represented a position in the sequence. They were encouraged to provide a response at each position. They could guess any given digit if they were unsure but could also record a dash for a ‘don’t know’ response if necessary. The recall interval had a duration of 15 s and, upon completion, the next trial commenced automatically. To alert participants to the start of the next trial, a 500 ms tone sounded 2 s before the recall interval expired.

In the with-concurrent articulation condition, on hearing the 500 ms tone preceding the first to-be-remembered item, participants were to begin and continue whispering the letters “x, y, z” repeatedly at the rate of approximately three letters per second while the to-be-remembered sequence was being presented and only ceased articulating to start writing their recall responses following the last to-be-remembered item. Before taking part in this condition, participants were trained to perform the concurrent articulation in the appropriate whispered fashion and at the required approximate rate. For this training phase only, the letters were presented repeatedly on the computer display at the rate of three per second (333 ms per letter) and participants were required to whisper each letter as it was presented. Following each iteration of the three letters there was a blank interval of a second in duration during which participants were required to continue whispering the letters as if they were still visible on the display. These blank intervals were incorporated to promote internally-guided pacing of the articulation. The no-concurrent articulation and with-concurrent articulation blocks were each preceded by two practice trials which were not accompanied by irrelevant sound. The two concurrent articulation blocks were completed on separate days but within a week of one another, with each session lasting approximately 50 min.

Results and discussion

In all experiments reported in this article, the raw data were scored using the standard strict serial recall criterion: An item was only recorded as correct if the serial position in which it was output matched its input serial position. In order to equate the number of datapoints per cell of the design ($n = 6$), only the steady-state/no-deviant and changing-state/no-deviant trials immediately preceding each steady-state/with-deviant and changing-state/with-deviant trial, respectively, were included in the analysis.

The proportion of correct responses (averaged across serial positions) for the eight conditions of Experiment 1a is shown in Fig. 2. As expected, serial recall was considerably poorer under concurrent articulation (Baddeley, 1986; Murray, 1968). In the absence of concurrent articulation, there was both a changing-state effect (poorer recall in the presence of changing-state sequences compared to steady-state sequences) and a deviation effect (poorer recall in the presence of sequences containing a deviant). Of key interest is how concurrent articulation affected the two forms of distraction: Consistent with previous studies, the changing-state effect was eliminated under concurrent articulation (Jones et al., 2004). The novel aspect of the data is that, contrary to the prediction of the WM-AC account but consistent with the task-engagement account, concurrent articulation also abolished the deviation effect.

This pattern of results was confirmed by a 2 (Concurrent articulation) × 2 (State) × 2 (Deviation) repeated-measures Analysis of Variance (ANOVA): There was a reliable main effect of Concurrent articulation, $F(1, 23) = 108.23$, $MSE = 0.05$, $p < .001$, $\eta_p^2 = 0.83$, a reliable main effect of State, $F(1, 23) = 9.05$, $MSE = 0.01$, $p = .006$, $\eta_p^2 = 0.28$, and a reliable main effect of Deviation, $F(1, 23) = 8.53$, $MSE = 0.01$, $p = .008$, $\eta_p^2 = 0.27$. Crucially, the two-way interactions suggested by the pattern evident in Fig. 2 were also reliable: there was a significant Concurrent articulation × State interaction, $F(1, 23) = 7.20$, $MSE = 0.01$, $p = .013$, $\eta_p^2 = 0.24$, and a significant Concurrent articulation × Deviation interaction, $F(1, 23) = 8.01$, $MSE = 0.01$, $p = .009$, $\eta_p^2 = 0.26$. The interaction effect observed was therefore larger than that on which we based our apriori power calculation ($\eta_p^2 = 0.15$) and thus the experiment, with $n = 24$, turned out to have somewhat greater power (.84) to detect the interaction than planned (.8). The Concurrent articulation × State interaction arose because, in the absence of concurrent articulation, there was a reliable changing-state effect, $F(1, 23) = 12.75$, $MSE = 0.01$, $p = .002$, $\eta_p^2 = 0.36$, which disappeared under concurrent articulation, $F(1, 23) = 0.42$, $MSE = 0.01$, $p = .525$, $\eta_p^2 = 0.02$. Similarly, the Concurrent articulation × Deviation interaction arose because there was a reliable deviation effect in the absence of concurrent articulation, $F(1, 23) = 17.00$, $MSE = 0.01$, $p < .001$, $\eta_p^2 = 0.44$, but not under concurrent articulation, $F < 1$. Finally, for the sake of completeness, we note that, in line with previous studies (Hughes et al., 2005, 2007; Marois et al., 2019), there was no State × Deviation interaction, $F(1, 23) = 0.55$, $MSE = 0.00$, $p = .467$, $\eta_p^2 = .02$, and neither was there a State × Deviation × Concurrent articulation three-way interaction, $F(1, 23) = 0.25$, $MSE =$

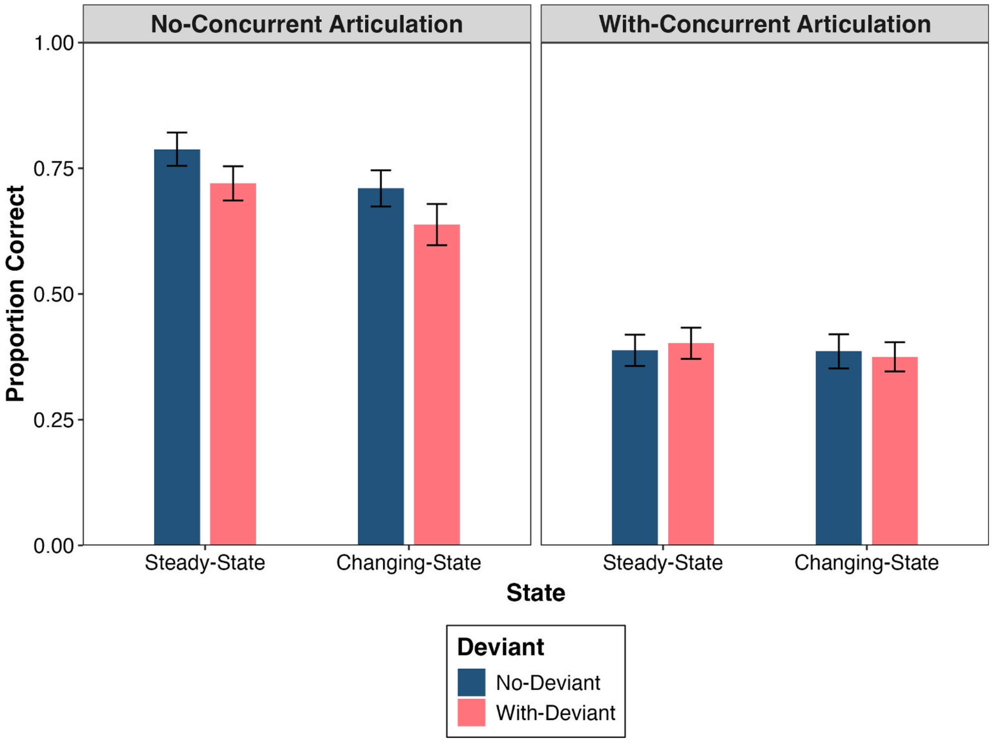

Fig. 2. Proportion correct serial recall in the eight conditions of Experiment 1a. Error bars represent the standard error of the mean.

0.01, $p = .621$, $\eta_p^2 = 0.01$.

Experiment 1a is the first to demonstrate that attentional capture by a deviant sound during serial recall, as well as disruption from changing-state sound, disappears under concurrent articulation. This contradicts the prediction of the WM-AC account that concurrent articulation should exacerbate deviant distraction given that the secondary activity would be expected to appropriate WM capacity needed to suppress distraction. Instead, the results are consistent with the task-engagement account: increased task-load triggers heightened task-engagement, which in turn shields performance from the deleterious effects of attentional capture (Hughes, 2014; Hughes et al., 2013).

It might be objected, however, that concurrent articulation itself impaired serial recall performance to such an extent that the deviation effect was eliminated simply because of an effective floor effect. Experiment 1b, therefore, sought to replicate the absence of the deviation effect (as well as the changing-state effect) under concurrent articulation using a design in which overall performance level should be considerably higher.

Experiment 1b

In Experiment 1b, we repeated the with-concurrent articulation conditions of Experiment 1a but shortened the length of the to-be-remembered list from 8 items to 6 in a bid to raise the general level of recall performance. Finding that the auditory distraction effects are again absent under concurrent articulation despite the expected marked increase in general performance levels would go against the notion that they were eliminated by concurrent articulation in Experiment 1a simply due to a floor effect.

Method

All aspects of the method were the same as Experiment 1a except for the following: A new sample of 16 participants were recruited from the campus community at Cardiff University. The to-be-remembered lists were six rather than eight digits in length (but still taken from the set 1–8). To maintain the same total list-presentation duration used in Experiment 1a despite the reduced list-length, the inter-stimulus interval between the to-be-remembered items was increased from 450 ms to 580 ms. This adjustment ensured that the auditory sequences retained the same overall duration and internal temporal parameters as in Experiment 1a. On with-deviant trials, the voice deviant occurred 365 ms after the third to-be-remembered item. We did not include a no-concurrent articulation condition in this experiment given that the observation of a changing-state effect and a deviation effect in the absence of concurrent articulation is not contentious and has already been replicated again in Experiment1a. Moreover, with six-digit lists in the absence of concurrent articulation, performance is likely to be close to ceiling in any case (e.g., Hanley & Bakopoulou, 2003). Thus, participants completed 90 trials divided into two blocks: a steady-state block (45 trials) and a changing-state block (45 trials), with no pause between blocks. Within each block, the six with-deviant sequences were presented on trials 5, 8, 18, 27, 35, and 41. As in Experiment 1a, block-order was counterbalanced across participants. Finally, to enhance the efficiency of data processing, participants in this experiment responded by typing the digits using the numeric keypad on the keyboard instead of writing them down.

Results and discussion

Fig. 3 shows recall performance in the four conditions of Experiment 1b. The first thing to note is that reducing the list-length clearly had the desired effect of raising performance levels generally, with average correct recall in this experiment reaching 58% correct compared to 39% in the corresponding (with-concurrent articulation) condition of Experiment 1a. Even with overall recall levels raised, the results replicate the key finding that there is no detrimental effect of either a deviant sound or changing-state sound under concurrent articulation. Confirming this, a 2 (State) × 2 (Deviation) ANOVA showed neither a main effect of State, $F(1, 15) = 0.27$, $MSE = 0.03$, $p = .614$, $\eta_p^2 = 0.02$, nor a main effect of Deviation, $F(1, 15) = 1.75$, $MSE = 0.01$, $p = .206$, $\eta_p^2 = 0.10$. There was a reliable interaction between these two factors on this

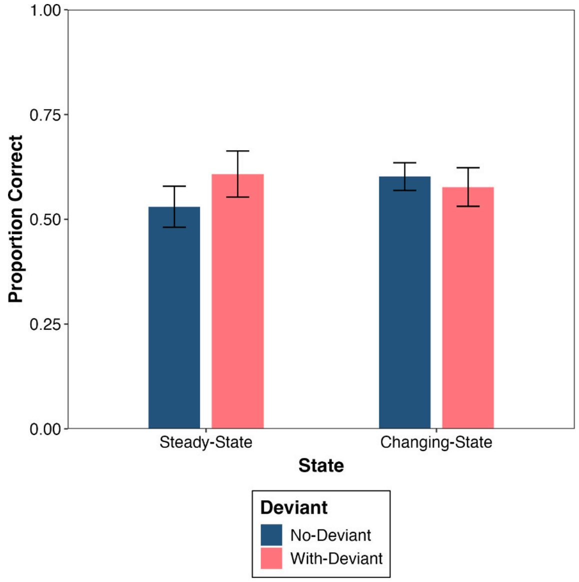

Fig. 3. Proportion correct recall in the four conditions of Experiment 1b. Error bars represent the standard error of the mean.

occasion, $F(1, 15) = 4.53$, $MSE = 0.01$, $p = .05$, $\eta_p^2 = 0.23$, where recall was somewhat *better* in the presence of a deviant in the context of a steady-state sequence, $F(1, 15) = 8.17$, $MSE = 0.01$, $p = .012$, $\eta_p^2 = 0.34$, but not in the context of a changing-state sequence, $F(1, 15) = 0.83$, $MSE = 0.01$, $p = .376$, $\eta_p^2 = 0.05$. We resist the temptation to speculate as to the reasons for this unexpected feature of the results, however, given that it has not been observed in several previous studies (Hughes et al., 2005, 2007; Marois et al., 2018), including the present Experiment 1a, and given that it was also not replicated in the present Experiment 2. The key point for present purposes is that the typical (negative) deviation effect, as well as the changing-state effect, was again absent under concurrent articulation despite an increase in overall performance level, suggesting that that the results of Experiment 1a were not the result of a floor effect. We note also that the experiment had ample power (.9) to detect a deviation effect had there been one, based on the size of the deviation effect observed in Experiment 1a ($\eta_p^2 = 0.27$).

Discussion of Experiments 1a and 1b

Experiment 1 showed that concurrent articulation eliminates not only the changing-state irrelevant sound effect (e.g., Jones et al., 2004) but also the deviation effect (e.g., Hughes et al., 2007) in serial recall. In line with previous theorizing, we suggest that concurrent articulation eliminates the changing-state sound effect because concurrent articulation severely impedes (if not blocks) the specific process—serial rehearsal—that also renders serial recall vulnerable to the changing-state effect (cf. AuBuchon et al., 2020; Jones et al., 2004). As noted earlier, proponents of the WM-AC account might also appeal to this mechanism to explain the abolition of the changing-state effect under concurrent articulation. However, it is not clear how the WM-AC account could explain why concurrent articulation also eliminates the deviation effect. There is ample evidence that the deviation effect is not restricted to serial-rehearsal based tasks (e.g., Hughes et al., 2007; Parmentier, 2008) and thus it is unlikely that the deviation effect was also eliminated via the effect of concurrent articulation on serial rehearsal (see also Experiment 2). As such, on the WM-AC account, the effect of concurrent articulation of imposing a cognitive load should have used up WM resources usually available to suppress distractors and hence exacerbate the degree of distraction (Kane et al., 2001; Lavie et al., 2004). This is opposite to what we observed. We suggest that concurrent articulation, in addition to specifically impeding serial rehearsal, imposes a general cognitive load which, rather than rendering a distinct WM system less able to suppress distractors, boosts overall task-engagement. This, in turn, shields against effects, such as the auditory deviation effect, that disrupt performance via momentary task-disengagement (through, e.g., attentional capture).

One potential objection to our interpretation thus far, however, could be based on the not uncommon view that concurrent articulation only impedes serial rehearsal and does not impose a nonspecific cognitive load at all (e.g., Baddeley, 1986; Camos et al., 2009; Cowan, 2001). First, however, recall that it has been claimed that even the mere act of co-ordinating two tasks (independently of any load imposed by each individually; i.e., the *cost of concurrence*; Navon & Gopher, 1979) imposes a cognitive load and does so sufficiently to increase the disruptive effect of distractors (e.g., Lavie et al., 2004). Thus, even if we were to take the view that concurrent articulation imposes no cognitive load in and of itself, the act of combining it with serial recall is indeed expected to increase such load. Moreover, having to rehearse a single digit—-which may be akin effectively to the repeated concurrent articulation of a single word—has also been argued to draw upon WM capacity needed to suppress distractors (Lavie et al., 2004). Second, in our view, the notion that concurrent articulation does not itself impose some cognitive load is, in any case, implausible; it seems very likely that setting up, initiating, and maintaining the articulatory motor programme involved in concurrent articulation incurs some cognitive cost (see Meiser & Klauer, 1999). Indeed, some computational accounts of short-term memory model the effect of concurrent articulation partly in terms of a general attentional load (Neath, 2000). Third, if concurrent articulation does not impose a nonspecific cognitive load, it is unclear why it eliminated the deviation effect. From this standpoint, it seems that the only plausible explanation that could offer a reprieve for the WM-AC account is that the deviation effect, like the changing-state effect, does specifically impair serial rehearsal, at least within the context of the serial recall task. Experiment 2 tests this possibility by examining whether concurrent articulation still eliminates the deviation effect even in a short-term memory task that does not require the retention of serial order and hence tends not to rely on serial rehearsal. This should allow us to witness any nonspecific cognitive load effect of concurrent articulation on the deviation effect, isolated from the specific effect of concurrent articulation on serial rehearsal.

Experiment 2

In this experiment, we again examine the impact of concurrent articulation on the deviation effect (as well as the changing-state effect) but this time using a missing-item task rather than serial recall. In the missing-item task, all but one of a well-known, closed, set of items is presented in a random order and the task on each trial is to identify which item was missing (e.g., ‘2’ is missing from the list ‘5, 8, 3, 6, 1, 4, 7, 9’). Whilst it is possible to use a serial rehearsal strategy for this task, the majority of participants tend not to, with the most commonly reported strategy being a ‘checking-off’ strategy in which the items are checked off a mental representation of the canonical series (1, 2, 3…) as the list unfolds (Beaman & Jones, 1997; Hughes & Marsh, 2020; Morrison et al., 2016). In line with the notion that a deviant does not specifically affect serial rehearsal, the missing-item task is as vulnerable to the deviation effect as is serial recall (e.g., Hughes et al., 2007). The missing-item task is not, however, vulnerable to the changing-state effect, unless participants happen to spontaneously adopt a serial rehearsal strategy, consistent with the view that changing-state stimuli specifically impair serial rehearsal (Hughes et al., 2007; Hughes & Marsh, 2020; Jones & Macken, 1993).

Moreover, concurrent articulation has much less effect on the missing-item task than it does on the serial recall task, in line with the notion that concurrent articulation affects serial recall at least partly by impeding serial rehearsal (Klapp et al., 1983; Macken & Jones, 1995). However, concurrent articulation should still, according to our view, impose a cognitive load in this (or any other) task. As such, the WM-AC account again predicts that the concurrent articulatory load should exacerbate the deviation effect whereas the task-engagement account predicts that it should again reduce or eliminate it.

It is important to highlight also that the task-engagement account does not necessarily expect the increase in load to translate into a detrimental main effect of concurrent articulation on performance. This follows because the function of the boost in task-engagement provoked by an increase in load is to minimise any deleterious effect of that increase. A classic demonstration of this was provided by Eggemeier et al. (1983) who found that as the difficulty of a task was increased, so too did participants' subjective assessments of load, and yet, despite this, performance levels stayed constant, in line with the notion that participants increased their level of engagement to offset the increased load. The central prediction the task-engagement account does make, however, is that the factor that elicits the boost in task-engagement should protect performance against factors that otherwise impair performance by diverting attention. In the present setting specifically, then, concurrent articulation should again reduce or eliminate the deviation effect but without necessarily having a direct deleterious effect on performance. At the same time, we expected to find a much reduced changing-state effect in the missing-item task (Elliott et al., 2016; Hughes et al., 2007; Jones & Macken, 1993).

Method

Participants

The sample-size was increased to 32 for this experiment on account of the fact that we were not only predicting a 'positive' effect on this occasion—an interaction between deviation and concurrent articulation (as in Experiment 1a)—but also predicting relatively small and possibly null detrimental main effects of concurrent articulation and of changing-state sound (Hughes et al., 2007; Klapp et al., 1983; Macken & Jones, 1995). According to GPower, a sample-size of 32 using the design of Experiment 2 affords .8 power (with alpha set at .05) to detect an effect with an η_p^2 of 0.042, a small-to-moderate sized effect. It also gave the experiment a power of .89 to detect an interaction between the deviation effect and concurrent articulation of the size observed in Experiment 1a ($\eta_p^2 = .26$). The participants were recruited from the participant pool at the University of Central Lancashire and all reported normal hearing and normal or corrected-to-normal vision. They took part in exchange for course credits or a small honorarium.

Apparatus and materials

The apparatus and materials were identical to those in Experiment 1a, with the following modifications: Participants completed a missing-item task in which they had to identify a missing digit from each visually presented sequence. Each sequence comprised eight digits sampled pseudo-randomly without replacement from the set 1–9. The missing digit was not the same digit across immediately successive trials. Unlike Experiment 1a (and 1b) in which the sequences could not end with the digit 8, the sequences in this experiment could end with any of the digits in the 1–9 set. Finally, each trial that featured a deviant sound involved a different missing digit.

Design

The design was the same as for Experiment 1a.

Procedure

The procedure was identical to Experiment 1a with the following exceptions: During each trial, eight digits from the set 1–9 were presented. Participants were required to write down the missing digit on a response sheet. As in Experiment 1, if participants were unsure, they were encouraged to guess. The recall interval was shortened to 10 s (compared to 15 s in Experiment 1a) given that only one digit needed to be output in this experiment. The testing session lasted approximately 40 min.

Results

Fig. 4 shows the proportion of items correctly identified as missing in the steady-state and changing state conditions, with and without a deviant, in the absence of concurrent articulation (left panel) and in the presence of concurrent articulation (right panel). It is apparent that in the absence of concurrent articulation, there was a deviation effect, but no changing-state effect, in line with our predictions and replicating several previous studies (e.g., Elliott et al., 2016; Hughes et al., 2007; Jones & Macken, 1993). Under concurrent articulation, however, there was no deviation effect, just as in Experiment 1 using serial recall, in line with the task-engagement account but at odds with the WM-AC account.

A 2 (Concurrent articulation) × 2 (State) × 2 (Deviation) within-participants ANOVA revealed that whilst the main effect of Deviation was not reliable, $F(1, 31) = 3.14$, $MSE = 0.03$, $p = .086$, $\eta_p^2 = 0.09$, this was because it interacted, as predicted, with Concurrent articulation, $F(1, 31) = 13.34$, $MSE = 0.01$, $p = .001$, $\eta_p^2 = 0.30$: The deviation effect was reliable in the absence of concurrent articulation, $F(1, 31) = 9.30$, $MSE = 0.03$, $p = .005$, $\eta_p^2 = 0.23$, but not with concurrent articulation, $F(1, 31) = 0.30$, $MSE = 0.03$, $p = .590$, $\eta_p^2 = 0.01$.

Whilst the main effect of Concurrent articulation was significant, $F(1, 31) = 10.23$, $MSE = 0.04$, $p = .003$, $\eta_p^2 = 0.25$, this effect, in contrast to the detrimental effect of concurrent articulation in Experiment 1 with serial recall, was a facilitatory one. However, note that this was not an overall beneficial effect of concurrent articulation on performance but rather an artefact of the reliable interaction between Concurrent articulation and Deviation reported above. That is, concurrent articulation benefitted performance solely by shielding it from the otherwise detrimental effect of a deviant: In the presence of a deviant, performance was better under concurrent articulation, $F(1, 31) = 14.29$, $MSE = 0.04$, $p = .001$, $\eta_p^2 = 0.31$, whereas no concurrent articulation effect was evident in the no-deviant condition, $F(1, 31) = 0.58$, $MSE = 0.04$, $p = .452$, $\eta_p^2 = 0.02$. As also predicted, there was no reliable main effect of State, $F(1, 31) = 0.77$, $MSE = 0.01$, $p = .388$, $\eta_p^2 = 0.02$, and neither did this factor interact with any other: State × Deviation, $F(1, 31) = 0.88$, $MSE = 0.01$, $p = .355$, $\eta_p^2 = 0.03$; Concurrent articulation × State, $F(1, 31) = 0.98$, $MSE = 0.02$, $p = .329$, $\eta_p^2 = 0.03$; Concurrent articulation × State × Deviation, $F(1, 31) = 0.23$, $MSE = 0.02$, $p = .638$, $\eta_p^2 = 0.01$.

Discussion

Experiment 2 showed that concurrent articulation eliminates the deviation effect in the context of a task (missing-item task) that is devoid of a requirement for serial order processing and in which participants therefore tend to adopt strategies other than serial rehearsal (e.g., Hughes & Marsh, 2020; Morrison et al., 2016). Two aspects of the results provide independent convergent evidence for the assumption that serial rehearsal was not a prominent strategy in the present experiment: First, there was no detrimental effect of concurrent articulation, consistent with previous studies showing relatively little effect of concurrent articulation in the missing-item task (Klapp et al., 1983; Macken & Jones, 1995). Second, there was no changing-state irrelevant sound effect, again replicating previous work (Elliott et al., 2016; Hughes et al., 2007; Jones & Macken, 1993; see also Beaman & Jones, 1997). Accordingly, the results of the current experiment go against the possibility that concurrent articulation may have eliminated the deviation effect in Experiment 1 because a deviant disrupts serial rehearsal and concurrent articulation strips the task of that serial rehearsal component.

Given the evidence that concurrent articulation did not affect a serial rehearsal strategy in the present experiment, we argue that concurrent articulation eliminated the deviation effect because it imposed a nonspecific cognitive load (e.g., Hughes et al., 2013). This is at odds with

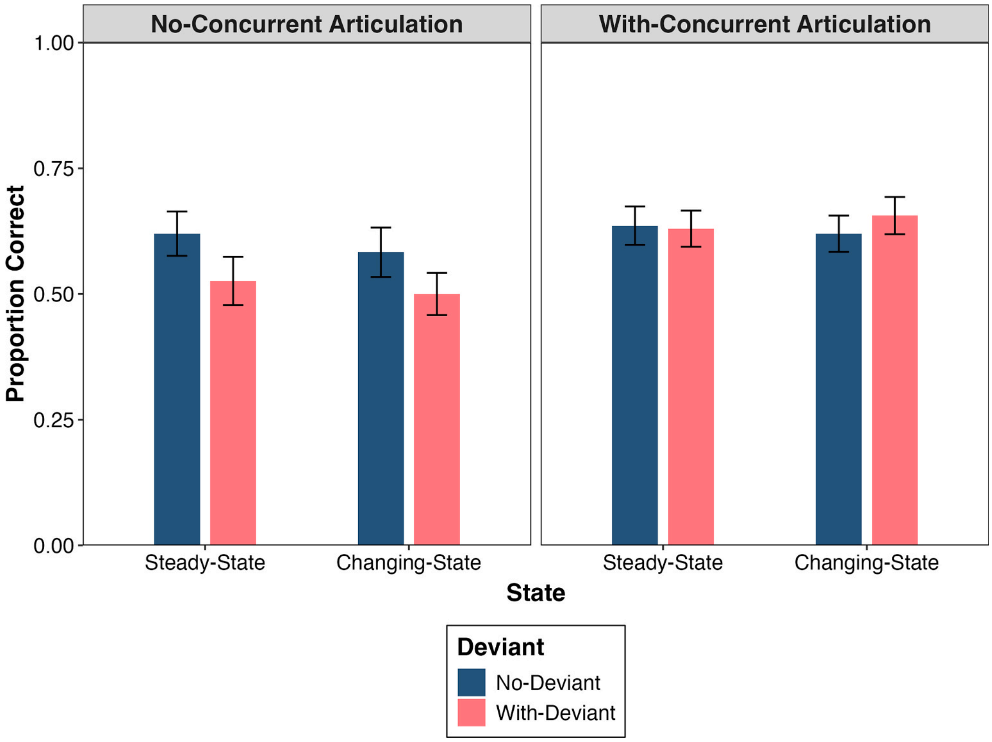

Fig. 4. Proportion of missing items correctly identified in the eight conditions of Experiment 2. Error bars represent the standard errors of the mean.

the WM-AC account, according to which the increased load should have drained WM capacity otherwise used to suppress the influence of distractors (e.g., De Fockert, 2013; Kane et al., 2001; Lavie et al., 2004). The results are instead in line with the task-engagement account (Hughes et al., 2013): Concurrent articulation had no (detrimental) main effect on performance and yet benefitted performance in the presence of a deviant. This pattern is entirely consistent with that reported previously in the context of an increase in visual-encoding load during serial recall: Increasing the difficulty of encoding to-be-remembered items by physically degrading them or by requiring participants to serially recall the local (high load) as opposed to global (low load) dimension of a series of Navon letters (Navon, 1977) has no detrimental main effect on serial recall itself but eliminates the susceptibility of serial recall to the deviation effect (Hughes et al., 2013; Marsh et al., 2020). The elimination of the deviation effect under articulatory suppression in the absence of a drop in general levels of performance in the articulatory suppression condition in this experiment also bolsters the case against the notion that its elimination in Experiment 1a was due to an effective floor or scalar effect.

General discussion

The current results offer a challenge to a widely held theoretical framework in which there exists a limited-capacity WM system which functions not only to temporarily store and process task-relevant information but also to attentionally control the influence of task-irrelevant and hence potentially distracting stimuli (Baddeley, 2007; De Fockert, 2013; Engle, 2002). The central general prediction of this view is that distraction should be a negative function of the availability of WM resources (e.g., Kane et al., 2001; Lavie et al., 2004; Unsworth & Engle, 2007). Thus, an increased load on WM due, for example, to having to carry out a concurrent task, should exacerbate distraction because the increased load leaves less capacity for WM to suppress distractors (e.g., Lavie et al., 2004). Experiment 1, however, showed that the disruptive effect of not only irrelevant changing-state sound but also of an irrelevant deviant sound is abolished, not exacerbated, under concurrent articulation. In Experiment 2, we examined a possible reprieve for the WM-AC account whereby it might be posited that the deviation effect, like the changing-state effect, is eliminated by concurrent articulation because the deviant specifically affects serial rehearsal and concurrent articulation strips the task of a serial rehearsal component. Using a missing-item task, in which serial rehearsal is a relatively infrequently adopted strategy, we again found that concurrent articulation eliminated the deviation effect. Bolstering our assumption that the missing-item task did not invoke much if any serial rehearsal, there was neither a detrimental main effect of concurrent articulation (cf. Klapp et al., 1983) nor a changing-state effect (cf. Hughes et al., 2007), both of which are widely thought to affect serial rehearsal. The results of Experiment 2 strongly converge with the evidence from Experiment 1 against the WM-AC account: Concurrent articulation imposes a nonspecific cognitive load but, rather than exacerbate auditory distraction during a short-term memory task, it eliminates it.

We suggest that the elimination of the deviation effect by concurrent articulation supports instead a task-engagement account of the relation between load and distraction. In this view, any increase in task-load can serve to boost participants' levels of task-engagement (cf. Eggemeier et al., 1983, Hockey 1997) and this in turn shields performance from certain forms of distraction (Hughes et al., 2013). The present study, together with previous work, suggests that increased engagement in *any* active, top-down, processing unrelated to the to-be-ignored stimuli—-whether it relates to the primary task or to the introduction of a secondary task (or possibly the mere co-ordination of two tasks; Navon & Gopher, 1979)—facilitates resistance to distraction. In addition, the fact that concurrent articulation has the same effect on the deviation effect as various kinds of high visual-encoding load (e.g., Hughes et al., 2013; Hughes & Marsh, 2019; Marsh et al., 2020) suggests against a potential reinterpretation of those encoding-load effects as perceptual load effects (Lavie, 1995) given that it is implausible to characterize concurrent articulation as an increase in perceptual load.

How then might the present findings and the task-engagement account be reconciled with studies showing that increased WM load can accentuate rather than attenuate distraction (e.g., De Fockert et al., 2001; Lavie et al., 2004; Muller-Gass & Schröger, 2007)? Here we offer a hypothesis based on the observation (made previously by SanMiguel et al., 2008) that in most of those studies the distraction is predicated on the distractors matching the participant's task-set despite being nominally 'task-irrelevant'. For instance, the task in Lavie et al. (2004) was to detect as quickly as possible whether a visually-presented target-letter was a *z* or an *x* while an accompanying (visual) distractor presented as a flanker was either incongruent with the required response (e.g., *Z* if the target was *x*), congruent with it (e.g., *Z* if the target was *z*), or neutral (an *N*). Similarly, in Dalton et al. (2009), participants made speeded judgments as to the spatial source of a noise-burst (high vs low) while an acoustically distinct distractor sound's spatial source was either congruent or incongruent with that of the target, and so on. While the fact that high WM load exacerbates distraction in these kinds of study has been taken classically as key support for the WM-AC view, a reasonable alternative interpretation seems possible based on the task-engagement account: A strengthening of the task-set (i.e., increased task-engagement) triggered by high load would be expected to heighten the activation of the representation of all stimuli that match that task-set, including that of distractors, thereby increasing, not decreasing, their distractive potency.

It has been claimed, however, that there are some instances in which increased distraction has been found under high WM load even when the task-irrelevant stimuli do not match the task-set (De Fockert, 2013). Again, however, many of these may also be explicable in terms of the task-engagement account. For example, high WM load exacerbates distraction from a colour-singleton distractor during a shape-based visual search task (e.g., Boot et al., 2005). Whilst colour is indeed irrelevant to the task-set in this case, the distractor may still be task-relevant at a less granular level, that is, at the level of the general goal to 'look out for a unique stimulus' (cf. *singleton detection mode*; Bacon & Egeth, 1994; Folk & Anderson, 2010). In other cases where increased WM load has been found to exacerbate distraction despite the distractors seemingly not matching the task-set, the distracting information was part of the target stimulus. For example, Muller-Gass and Schröger (2007) asked participants to make a speeded response to whether a tone was short or long in duration (low WM load) or whether it had the same or a different duration to the previous tone (high WM load). On rare occasions, the tone deviated in terms of pitch. Consistent with the WM-AC account, they found that the pitch-deviation impaired performance to a greater extent under high load. However, in this case the 'to-be-ignored' input could still be deemed task-relevant because it is an integral part of the target stimulus. Again, therefore, a heightened task-set due to high load may enhance the processing of the 'task-irrelevant' input in this case thereby making it more, not less, distracting; indeed, this was Muller-Gass and Schröger's (2007) own interpretation: "greater attention to the task-relevant stimulus (which also contains the distractor information) enhances the processing of all stimulus information, including the auditory change" (p. 175).[2] The same interpretation may also apply to the finding that the Ebbinghaus illusion—whereby a central 'target' circle looks smaller when surrounded by larger 'inducer' circles than when surrounded by smaller inducer circles (e.g., Coren & Miller, 1974)—is enhanced under high WM load (De Fockert & Wu, 2009). An important feature of this illusion in the context of the current discussion is that the inducer circles are typically perceived as part of the same perceptual object as the target circle, as evident from the fact that the illusion is diminished if they are not, such as when the inducer stimuli are angular shapes rather than circles (Coren & Miller, 1974; Choplin & Medin, 1999). Again, therefore, using the standard version of the Ebbinghaus stimulus, increased task-engagement under high WM load would be expected to strengthen the processing of the inducers, not just of the central circle, thereby enhancing the illusion.[3]

In contrast to the majority of studies in which WM load increased distraction or task-irrelevant processing, in the studies that have found high WM load to reduce distraction, the task-irrelevant stimuli do not distract on account of their matching the task-set (or by being part of the target stimulus) but rather by drawing attention away from the current task-set, i.e., by causing task-*disengagement* (present study; Berti & Schröger, 2003; SanMiguel et al., 2008). Thus, setting up conditions that make engagement with the focal task stronger or more steadfast (e.g., high load) reduces such distraction because it circumvents the mechanism—task-disengagement—by which the distractor usually exerts its effect.

There appears to be nothing within the WM-AC account to suggest that increased WM load should only exacerbate distraction when the distractors are effectively task-relevant (and certainly nothing to suggest that distraction from truly task-irrelevant distractors should be reduced under high WM load). Indeed, such a view would be at odds with the fact that most of the studies that have found a negative correlation between distractibility and WM capacity (e.g., Engle, 2002)—the other key line line of evidence cited in support of the WM-AC account (e.g. De Fockert, 2013)—have involved truly task-irrelevant distraction such as the deviation effect (as used in the present study; e.g., Hughes et al., 2013; Sörqvist, 2010b), distraction from hearing one's own name during a shadowing task (Conway et al., 2001), and from other kinds of meaningful speech during free recall (Beaman, 2004). At first glance, a clear exception to this is that interference in the classic color-word Stroop task is also negatively related to differences in WM capacity (Kane & Engle, 2003), a form of distraction where the 'distractor' (the word-meaning) clearly matches the task-set to name a colour. However, closer scrutiny has revealed that, in fact, low-WM capacity individuals are only more susceptible to failing to maintain the goal-component of the task-set in the Stroop paradigm, i.e., remembering to name the colour rather than read the word, a component indexed by the inadvertent reporting of the word (i.e., an intrusion error) or slower RTs on incongruent trials but only at the tail of the RT distribution (i.e., an increase only in the number of very slow responses). There are not, in contrast, WM capacity-related individual differences in the response-competition component of Stroop distraction (i.e., the Stroop effect 'proper'; e.g., Morey et al., 2012; Unsworth et al., 2012; see also Keye et al., 2009; Redick et al., 2011). Moreover, such individual differences in WM capacity may also be amenable to a task-engagement analysis: Individuals with a greater trait ability to maintain high active-engagement would be expected to be better both at WM span tasks in which two goals—that relating to the storage component and that relating to the processing component of such tasks—need to be co-ordinated and also at resisting task-disengagement types of distraction (see also MacLeod et al., 2003).

A question raised during the peer review process concerns whether the task-engagement account must be treated as incompatible with the

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[2] Berti and Schroger (2003) used the same basic paradigm and yet, as noted in the Introduction, found reduced distraction under high 'WM load'. However, they used an *n*-back task in which, in the high load condition, the response required was based solely on tone $n - 1$. It seems possible that having to increase task-engagement due to having to continuously respond to the *previous* tone may not have the same spreading effect onto the irrelevant dimensions of the *current* tone as when the current tone also forms a basis for the response (Muller-Gass & Schroger, 2007), allowing thereby the attenuating effect of high cognitive load/task-engagement on distraction to manifest.

[3] A further observation cited as support for WM-AC is that the detection of a one-off task-irrelevant visual stimulus is enhanced—i.e., a reduction of *inattentional blindness* (Mack & Rock, 1998—under high WM load (De Fockert & Bremner, 2011). It is worth noting, however, that such studies do not show (or test for) increased distraction per se but merely the enhanced processing of task-irrelevant input. Moreover, some studies have, in any case, shown that high WM load can *increase* inattentional blindness, contrary to the WM-AC view and in line with the task-engagement account (Fougnie and Marois, 2007; Todd et al., 2005). Thus, further research will clearly be required to adjudicate between the two accounts in the context of inattentional blindness.

WM-AC account, or whether WM-AC could instead be extended to incorporate a compensatory upregulation of task engagement under high cognitive load, thereby accommodating instances—such as those observed here—in which high load reduces rather than increases distraction. It is worth noting first that, to the best of our knowledge, such an extension has not to date been articulated within the WM-AC framework itself. Second, it is not clear how it could be incorporated without substantial theoretical cost. Extending WM-AC to predict that high load can reduce distraction by invoking a compensatory task-engagement mechanism risks rendering the account difficult to test, as it could then accommodate both increases and reductions in distraction under high load without a clear principle for predicting when each outcome should occur. We suggest instead that assuming a compensatory task-engagement mechanism that is not necessarily constrained by a discrete capacity-limited WM system provides a more parsimonious account of the present findings.

Another possibility is that the manipulation of cognitive load in the present study did not tax WM capacity sufficiently to show the increase in distraction predicted by the WM-AC account. That is, a relatively modest increase in cognitive load may facilitate task performance (possibly by boosting task-engagement as we have argued) but as cognitive load is increased further a point is reached where it impairs performance. However, this interpretation sits uneasily with a central body of evidence that has motivated WM-AC, namely the robust finding that individual differences in WM capacity are correlated with distractibility under task conditions that do not involve performance collapse (e.g., De Fockert et al., 2001; Kane et al., 2001; Kane & Engle, 2003). Such correlational evidence relies on limitations in attentional control being expressed across a range of task demands, rather than only at the point of near-ceiling load. If increased distraction were to emerge only when capacity is exhausted, then distractibility would be expected to show little variance across individuals until that point, making it difficult to obtain the graded associations between WM capacity and distraction that are commonly reported in the literature.

Moreover, the present findings do not merely reflect an absence of increased distraction under higher task demands, but rather a systematic *reduction* in distraction as load increased. While appeals to residual capacity or insufficient load might plausibly account for null effects, they do not readily explain why distraction should decrease with increasing task demands unless additional compensatory mechanisms are assumed. As discussed above, introducing such mechanisms into WM-AC carries substantial theoretical cost, as it undermines the framework's core prediction regarding the direction of load effects on distraction. Consistent with this concern, WM-AC has previously been used to explain increases in distraction under relatively modest load manipulations, including cases in which the mere coordination of two tasks—the so-called "cost of concurrence"—was sufficient to increase distractibility relative to a no-load baseline (Lavie et al., 2004). More generally, we are not aware of evidence for a non-monotonic relation between task load and distraction within the WM-AC literature. Taken together, these considerations suggest that restricting WM-AC predictions to conditions of extreme or near-collapse load substantially narrows the theory's explanatory scope and is difficult to reconcile with both its empirical foundations and the direction of the effects observed here.

Before concluding, we think it worth highlighting a further, methodological, implication and application of the current results. As mentioned earlier, several theorists have suggested that concurrent articulation does not impose much if any nonspecific cognitive load (Baddeley, 1986; Camos et al., 2009; Cowan, 2001). As such, concurrent articulation is often used as a technique for selectively impeding serial articulatory rehearsal and indeed we ourselves have argued in the present paper and elsewhere that this is how concurrent articulation eliminates the changing-state effect in serial recall (Hughes, 2025; Jones et al., 2004). However, the present findings pertaining to the deviation effect suggest that the assumption that concurrent articulation does not impose a nonspecific cognitive load is unsafe: If concurrent articulation is wholly automatic (i.e., does not involve attentional control) it is far from clear why it would eliminate the deviation effect, which all theorists agree is an attentional effect. It is thus important that any influence of this increased load is assessed in studies that use concurrent articulation to examine the role of articulatory rehearsal, or more generally, inner speech, in memory research and beyond (cf. Emerson & Miyake, 2003; Nedergaard et al., 2023), particularly given the growing interest in this area (Fernyhough & Borghi, 2023). Some attempts to do this include using a control secondary task that is similar to concurrent articulation in some respects but might not (at least on some theoretical accounts) be expected to interfere with articulatory serial rehearsal, such as finger or foot tapping (e.g., Alloway et al., 2010). And indeed, the fact that concurrent articulation tends to impair verbal serial recall more than concurrent tapping and that the opposite is the case in visuo-spatial recall (Alloway et al. 2010, Meiser & Klauer, 1999; but see Jones et al., 1995) bolsters the view that concurrent articulation does have a specific effect on articulatory rehearsal (which is more likely to be used in a verbal than visuo-spatial recall task). However, an independent test of whether the control task imposes as much nonspecific cognitive load as concurrent articulation is not typically conducted and it is possible that concurrent articulation in some if not all settings exerts at least some of its effect through an increase in nonspecific cognitive load rather than through its specific effect of impeding articulatory rehearsal/inner speech. The deviation effect now offers such an independent test: The degree to which a secondary activity imposes a general cognitive load can be indexed by the degree to which it reduces the deviation effect.

To conclude, we argue that the present findings are at odds with the notion that a cognitive load draws upon the capacity of a distinct WM system required to maintain task priorities in the face of distraction. Attentional capture by an auditory deviant was found to be eliminated rather than exacerbated when participants had to undertake a secondary task concurrently with a short-term memory task (serial recall, Experiment 1; missing-item task; Experiment 2). We argue that such attenuation of distraction can be explained by supposing that high task-load promotes a boost in active task-engagement that acts to counter distraction effects that are caused by task-disengagement. Finally, a hypothesis was offered as to how this account could also provide an alternative explanation of numerous cases in which high WM load has been found to increase rather than reduce distraction. One obvious direction for future research will be to put this hypothesis to the test.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this manuscript, the authors used a generative AI tool (ChatGPT) to assist with checking and improving drafts of sentences and paragraphs for concision and clarity. The same tool was also used to generate the cartoon figures included in Fig. 1. After using these tools, the authors reviewed and edited all content as necessary and take full responsibility for the content of the published article.

CRediT authorship contribution statement

Robert W. Hughes: Writing – review & editing, Writing – original draft, Supervision, Resources, Project administration, Methodology, Funding acquisition, Conceptualization. **Mark J. Hurlstone:** Writing – review & editing, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **John E. Marsh:** Writing – review & editing, Software, Resources, Project administration, Methodology, Investigation, Data curation, Conceptualization. **Dylan M. Jones:** Writing – review & editing, Supervision, Resources.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

The data and analysis scripts for all three experiments reported in this article are openly available at https://github.com/mark-hurlstone/Hughes-et-al-2025

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