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REDUCTION OF ENVIRONMENTAL DISTRACTION TO FACILITATE COGNITIVE PERFORMANCE

Topic Editor
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REDUCTION OF ENVIRONMENTAL DISTRACTION TO FACILITATE COGNITIVE PERFORMANCE

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Eye-closure helps concentration.
The owner of the image is Dr Timothy J. Hollins.

When faced with a difficult task, people often look at the sky or close their eyes. This behavior is functional: the reduction of distractions in the environment can improve performance on cognitive tasks, including memory retrieval. Reduction of visual distractions can be operationalized through eye-closure, gaze aversion, or by comparing exposure to simple and complex visual displays, respectively. Reduction of auditory distractions is typically examined by comparing performance under quiet and noisy conditions. Theoretical reasoning regarding this phenomenon draws on various psychological principles, including embodied cognition, cognitive load, and modality-specific interference. Practical applications of the research topic are diverse. For example, the findings could be used to improve performance in forensic settings (e.g., eyewitness testimony), educational settings (e.g., exam performance), occupational settings (e.g., employee productivity), or medical settings (e.g., medical history reporting). This Research Topic welcomes articles from all areas of psychology relating to the reduction of distractions to improve task performance. Articles can address (but are not limited to) new empirical findings, comprehensive reviews, theoretical frameworks, opinion pieces, or discussions of practical applications.

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EDITORIAL
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Reduction of environmental distraction to facilitate cognitive performance

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Keywords: distraction, cognitive load, modality-specific interference, eye-closure, eyewitness memory

INTRODUCTION

Imagine explaining a statistics problem to a student while your colleague at the back of the room is frantically waving to get your attention. Or imagine reporting to a police officer on the street what happened during a witnessed mugging, while seeing traffic buzz by and hearing snippets of conversations from passers-by. Environmental distractions can have an impact on cognitive performance, whether this concerns solving a mathematical problem, maintaining a conversation, or retrieving an experienced event from memory. Glenberg et al. (1998) were the first to systematically explore the relationship between memory, environmental distraction, and behavioral control of distraction through gaze aversion and eye-closure. In a series of experiments, they found that people are more likely to avert their gaze when trying to answer more difficult questions about general and autobiographical information. Moreover, they found that instructed eye-closure resulted in better performance on a word recall task, whereas watching a silent movie resulted in poorer performance. Inspired by this work, Wagstaff et al. (2004) and Perfect et al. (2008) examined whether instructed eye-closure could also improve recall of events. In a series of studies, they found that eye-closure substantially improved the amount and accuracy of information reported about witnessed events.

THEORETICAL ISSUES

Different mechanisms have been proposed to explain the eye-closure effect, which can be divided into two broad categories: general versus modality-specific. The general-distraction explanation is based on Glenberg's (1997) embodied cognition account of memory, which holds that environmental monitoring and cognitive tasks such as memory retrieval compete for cognitive resources. Disengaging from the environment (e.g., through eye-closure) allows us to reallocate cognitive resources to the task at hand, thus improving performance, but at the potential cost of poorer monitoring of the current environment. The general-distraction explanation of the eye-closure effect is supported by findings that, in some studies, eye-closure improved recall of both visual and auditory information (e.g., Perfect et al., 2008, Experiments 4 and 5; Vredeveldt and Penrod, 2013, free recall). It is also supported by the finding that eye-closure can reduce the cross-modal memory impairment caused by auditory distraction (Perfect et al., 2011). The modality-specific explanation, on the other hand, holds that distractions in the environment only interfere with concurrent tasks in the same modality, consistent with Baddeley and Hitch's (1974) working memory model (see also Baddeley and Andrade, 2000). This explanation is supported by findings that, in some studies, eye-closure improved recall only for visual details (e.g., Perfect et al., 2008, Experiment 2; Vredeveldt et al., 2012; Vredeveldt and Penrod, 2013, cued recall). Further, recall of visual details is most disrupted by visual distraction, whereas recall of auditory details is most disrupted by auditory distraction (Vredeveldt et al., 2011). All in all, it seems likely that both general and modality-specific processes are involved in the effect of environmental distraction on cognitive performance.

Although the role of modality has received much research attention, other aspects of the nature of the distraction are relatively less well-investigated. In this Research Topic, issues such as the social aspects of environmental distractions (Buchanan et al., 2014), and the relevance of the distraction to pending goals (Scheiter et al., 2014) and other tasks (Weeks and Hasher, 2014) are further explored. In addition, different aspects of performance are addressed, such as response criterion (Rae and Perfect, 2014) and other metacognitive indices (Beaman et al., 2014). We also learn more about the neural basis of the effect of distraction on performance (Wais and Gazzaley, 2014).

APPLIED ISSUES

Research on the effect of distraction on cognitive performance has clear practical implications. In educational settings, students must remember large quantities of information to perform well on examinations. In medical settings, doctors often rely on patients' memory reports to establish medical histories and identify appropriate treatment options. In legal settings, information provided by eyewitnesses plays a pivotal role in police investigations and legal decisions. With respect to the latter, many interviewing procedures have been developed to help witnesses remember more, and some have been found to be highly successful, such as the Cognitive Interview (Fisher and Geiselman, 1992) and the NICHD protocol (Orbach et al., 2000). However, practical implementation of such complex protocols has proven difficult (e.g., Clarke and Milne, 2001). The Eye-Closure Interview (Vredeveldt et al., submitted) could prove to be a feasible and effective alternative. Indeed, findings from studies in which the eye-closure instruction was tested under naturalistic conditions (Vredeveldt and Penrod, 2013) and in a field setting (Vredeveldt et al., submitted) seem promising.

Several contributions in the Research Topic specifically focused on practical applications. For example, Scheiter et al. (2014) examined how distraction affects students' learning in educational hypermedia environments. Hyman et al. (2014) explored the impact of talking on the phone on walking behavior, an all-too-common form of distraction that exemplifies the trade-off between attention to the internal and external worlds discussed by Glenberg (1997). Additionally, two articles investigated the effectiveness of reducing distraction through eye-closure in interviews with child witnesses (Kyriakidou et al., 2014; Mastroberardino and Vredeveldt, 2014).

CONCLUSION

The aims of this Research Topic were two-fold: (1) to enhance our understanding of the mechanisms involved in the effects of distraction on cognitive performance, and (2) to identify methods that successfully reduce environmental distractions, thus facilitating cognitive performance in applied settings. The articles present state-of-the-art research providing novel insights into these key questions, and Craik's (2014) commentary constitutes an excellent critical review of this important work. In all, the contributions in this Research Topic advance our knowledge of both theoretical and applied aspects of the effects of environmental distraction on cognitive performance. Understanding how distraction affects performance, and how we can effectively reduce the impact of distraction, could prove fruitful in improving cognitive performance in a wide range of applied settings. Procedures such as eye-closure or noise reduction may assist students to concentrate on their exams, help witnesses to remember more about criminal events, and could improve the reader's chances of winning their next pub quiz, though whether they would enjoy a distraction-free pub environment is another matter.

REFERENCES

Baddeley, A. D., and Andrade, J. (2000). Working memory and the vividness of imagery. *J. Exp. Psychol. Gen.* 129, 126–145. doi: 10.1037/0096-3445.129.1.126

Baddeley, A. D., and Hitch, G. J. (1974). "Working memory," in *Recent Advances in Learning and Motivation,* ed G. A. Bower (New York, NY: Academic Press), 47–89.

Beaman, P., Hanczakowski, M., and Jones, D. M. (2014). The effects of distraction on metacognition and metacognition on distraction: evidence from recognition memory. *Front. Psychol.* 5:439. doi: 10.3389/fpsyg.2014.00439

Buchanan, H., Markson, L., Bertrand, E., Greaves, S., Parmar, R., and Paterson, K. B. (2014). Effects of social gaze on visual-spatial imagination. *Front. Psychol.* 5:671. doi: 10.3389/fpsyg.2014.00671

Clarke, C., and Milne, R. (2001). *National Evaluation of the PEACE Investigative Interviewing Course*. Police Research Award Scheme. London: Home Office.

Craik, F. I. M. (2014). Effects of distraction on memory and cognition: a commentary. *Front. Psychol.* 5:841. doi: 10.3389/fpsyg.2014.00841

Fisher, R. P., and Geiselman, R. E. (1992). *Memory-Enhancing Techniques for Investigative Interviewing: the Cognitive Interview*. Springfield, MA: Charles Thomas.

Glenberg, A. M. (1997). What memory is for: creating meaning in the service of action. *Behav. Brain Sci.* 20, 1–55. doi: 10.1017/S0140525X97470012

Glenberg, A. M., Schroeder, J. L., and Robertson, D. A. (1998). Averting the gaze disengages the environment and facilitates remembering. *Mem. Cognit.* 26, 651–658. doi: 10.3758/BF03211385

Hyman, I. E. Jr., Sarb, B. A., and Wise-Swanson, B. M. (2014). Failure to see money on a tree: inattentional blindness for objects that guided behavior. *Front. Psychol.* 5:356. doi: 10.3389/fpsyg.2014.00356

Kyriakidou, M., Blades, M., and Carroll, D. (2014). Inconsistent findings for the eyes closed effect in children: the implications for interviewing child witnesses. *Front. Psychol.* 5:448. doi: 10.3389/fpsyg.2014.00448

Mastroberardino, S., and Vredeveldt, A. (2014). Eye-closure increases children's memory accuracy for visual material. *Front. Psychol.* 5:241. doi: 10.3389/fpsyg.2014.00241

Orbach, Y., Hershkowitz, I., Lamb, M. E., Sternberg, K. J., Esplin, P. W., and Horowitz, D. (2000). Assessing the value of structured protocols for forensic interviews of alleged child abuse victims. *Child Abuse Negl.* 24, 733–752. doi: 10.1016/S0145-2134(00)00137-X

Perfect, T. J., Andrade, J., and Eagan, I. (2011). Eye-closure reduces the cross-modal memory impairment caused by auditory distraction. *J. Exp. Psychol. Learn. Mem. Cogn.* 37, 1008–1013. doi: 10.1037/a0022930

Perfect, T. J., Wagstaff, G. F., Moore, D., Andrews, B., Cleveland, V., Newcombe, S., et al. (2008). How can we help witnesses to remember more? It's an (eyes) open and shut case. *Law Hum. Behav.* 32, 314–324. doi: 10.1007/s10979-007-9109-5

Rae, P. J. L., and Perfect, T. J. (2014). Visual distraction during word-list retrieval does not consistently disrupt memory: no evidence for a finite cognitive resource theory. *Front. Psychol.* 5:362. doi: 10.3389/fpsyg.2014.00362

Scheiter, K., Gerjets, P., and Heise, E. (2014). Distraction during learning with hypermedia: difficult tasks help to keep task goals on track. *Front. Psychol.* 5:268. doi: 10.3389/fpsyg.2014.00268

Vredeveldt, A., Baddeley, A. D., and Hitch, G. J. (2012). The effects of eye-closure and "ear-closure" on recall of visual and auditory aspects of a criminal event. *Eur. J. Psychol.* 8, 284–299. doi: 10.5964/ejop.v8i2.472

Vredeveldt, A., Hitch, G. J., and Baddeley, A. D. (2011). Eyeclosure helps memory by reducing cognitive load and enhancing visualisation. *Mem. Cognit.* 39, 1253–1263. doi: 10.3758/s13421-011-0098-8

Vredeveldt, A., and Penrod, S. D. (2013). Eye-closure improves memory for a witnessed event under naturalistic conditions. *Psychol. Crime Law* 19, 893–905. doi: 10.1080/1068316x.2012.700313

Wagstaff, G. F., Brunas-Wagstaff, J., Cole, J., Knapton, L., Winterbottom, J., Crean, V., et al. (2004). Facilitating memory with hypnosis, focused meditation, and eye closure. *Int. J. Clin. Exp. Hypn.* 52, 434–455. doi: 10.1080/00207140490889062

Wais, P. E., and Gazzaley, A. (2014). Distractibility during retrieval of long-term memory: domain-general interference, neural networks and increased susceptibility in normal aging. *Front. Psychol.* 5:280. doi: 10.3389/fpsyg.2014.00280

Weeks, J. C., and Hasher, L. (2014). The disruptive - and beneficial - effects of distraction on older adults' cognitive performance. *Front. Psychol.* 5:133. doi: 10.3389/fpsyg.2014.00133

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The effects of distraction on metacognition and metacognition on distraction: evidence from recognition memory

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The effects of auditory distraction in memory tasks have, to date, been examined with procedures that minimize participants' control over their own memory processes. Surprisingly little attention has been paid to metacognitive control factors which might affect memory performance. In this study, we investigate the effects of auditory distraction on metacognitive control of memory, examining the effects of auditory distraction in recognition tasks utilizing the metacognitive framework of Koriat and Goldsmith (1996), to determine whether strategic regulation of memory accuracy is impacted by auditory distraction. Results replicated previous findings in showing that auditory distraction impairs memory performance in tasks minimizing participants' metacognitive control (forced-report test). However, the results revealed also that when metacognitive control is allowed (free-report tests), auditory distraction impacts upon a range of metacognitive indices. In the present study, auditory distraction undermined accuracy of metacognitive monitoring (resolution), reduced confidence in responses provided and, correspondingly, increased participants' propensity to withhold responses in free-report recognition. Crucially, changes in metacognitive processes were related to impairment in free-report recognition performance, as the use of the "don't know" option under distraction led to a reduction in the number of correct responses volunteered in free-report tests. Overall, the present results show how auditory distraction exerts its influence on memory performance via both memory and metamemory processes.

Keywords: metacognition, memory, recognition, auditory distraction, irrelevant speech

INTRODUCTION

Distraction, whether in the form of external stimuli or self-generated thoughts, accompanies a vast spectrum of our everyday activities. Much of this can be avoided by relatively simple actions, like closing one's eyes if the distraction is visual, but some forms of distraction cannot be done away with so easily. Auditory distraction in particular is impossible to avoid unless we have control over the source of distraction, or else access to noise-reduction technology (e.g., headsets). If we do not have such control, for example, when we are in a supermarket and music plays over the store's loudspeakers, our cognitive processes need to unfold in the presence of distraction. This can constitute a serious problem inasmuch as numerous studies have found that the efficacy of cognitive processes suffers in the presence of auditory distraction (see reviews by Hughes and Jones, 2003; Beaman, 2005a; Jones et al., 2010). Most relevantly to the purpose of the present study, decades of studies of memory processes have found that auditory distraction present either at encoding or retrieval negatively impacts upon memory performance (e.g., Broadbent, 1982; Salamé and Baddeley, 1982, 1986; Miles et al., 1991; Jones and Macken, 1993; Elliott and Cowan, 2005; Bell et al., 2013).

Although the negative impact of auditory distraction upon memory performance is well-documented, what still remains unexplored is how people strive to adapt to auditory distraction they cannot avoid. Recent developments in theoretical approaches to memory processes stress that memory processes are far from passive, rather they are subject to a number of control operations. A metacognitive approach to memory describes how people monitor their memory performance under a variety of conditions and how the products of metacognitive monitoring are employed in an attempt to optimize memory performance (see Koriat, 2007, for a review). Thus, for example, people try to establish whether encoding of information is satisfactory and, whenever this process of monitoring informs them that certain information is poorly learned, additional study time may be allocated to this information (Thiede and Dunlosky, 1999). Similarly, during retrieval people monitor whether retrieved information is likely to be correct and whenever this process of monitoring informs them that certain information may be incorrect people may choose to withhold it from a memory report (Koriat and Goldsmith, 1996; Higham, 2007). The question that we begin to address here is how the processes of metacognitive monitoring and control at test are affected by, and feed back onto, auditory distraction. Suppose effective metacognitive monitoring and control allows individuals to compensate for the impact of distraction (interpreted here as an outcome). Discovering the circumstances under which this is possible would demonstrate the effects of metacognition on distraction and would constitute a practical as well as a theoretical advance. Alternatively, suppose that effective metacognitive monitoring and control becomes more difficult when distracted (i.e., being in the *state* of distraction), the monitoring of output may be disturbed as much as the initial encoding of items in a memory task, for example. This would demonstrate an impact of distraction on metacognition.

To describe how people monitor the accuracy of the products of retrieval processes and how they exert metacognitive control, Koriat and Goldsmith (1996) developed a framework within which to examine the decisions made as to whether retrieved information should be volunteered or withheld from a memory report. In this framework it is assumed that responding to a memory question unfolds in three steps. At the first step, a person accesses memory to generate the best, or most likely, candidate response to the question. In the next step, the person monitors the retrieval process, assigning confidence that his/her best candidate response is correct [assigning confidence in this way may be either a strategic or a wholly unconscious process – we are ambivalent on this point. Koriat and Goldsmith (1996) use the more strategic-sounding term "assessing probability" to describe this process but there is no necessary assumption that the person is making subjective probability judgments either consciously or deliberately, (see also Goldsmith et al., 2014)]. Finally, in the third step, the person compares the confidence for a given candidate response to a criterial or threshold level of confidence which warrants volunteering of candidate responses in a memory report. If confidence in the correctness of a given candidate response is higher than criterion, this candidate response is volunteered. However, if confidence in the correctness of this candidate response is lower than criterion, it is withheld and the individual responds "don't know" to the memory question (see **Figure 1**).

Crucially, this framework postulates that, whenever withholding responses is allowed, the ultimate memory performance observed is jointly shaped by memory processes responsible for generating candidate responses and metacognitive processes responsible for deciding which candidate responses should be volunteered. Koriat and Goldsmith (1996) describe two different indices of memory performance. The input-bound accuracy (IBA) measure refers the number of correct responses in a test relative to the number of questions asked (which is usually equivalent to the number of items presented for study). Essentially, it is a measure of the *quantity* of correct information volunteered at output. Thus, for example, if persons A and B are given 20 questions and respond correctly to five of these, then the IBA measure for both these individuals is 25%. The output-bound accuracy (OBA) measure refers the number of correct responses in a test relative to the overall information that a person provides in this test. Essentially, it is a measure of the *quality* of memory output. Thus, if A declines to answer 15/20 questions then A's OBA is 100%, whereas if B responds incorrectly to five of the questions, then B's OBA measure is 50%. Although in a forced-report test IBA and OBA

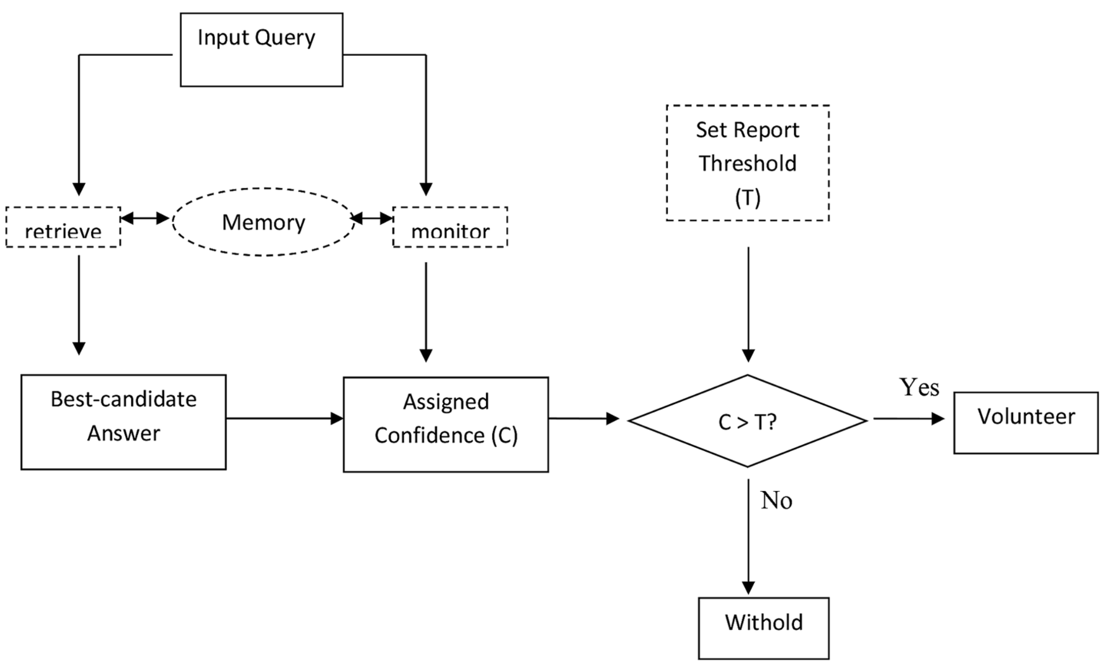

FIGURE 1 | How distraction might affect metacognition and metacognition might affect distraction. Adapted from Goldsmith et al. (2014). Dashed boxes represent operations which might be affected by distraction. Memory, its retrieval or monitoring processes might be disrupted by distraction, and the meta-cognitive process of setting a response threshold might mediate the impact of distraction. Note that if distraction lowers confidence in an output, then this will have the same negative effect on volunteering the item as raising the report threshold for that output.

measures are necessarily identical, in free-report they become different measures of memory performance, sensitive to changes in metacognitive processes.

In their seminal paper, Koriat and Goldsmith (1996) described several scenarios by which changes in memory and/or metacognitive processes affect IBA and OBA measures. Changes in underlying memory have quite straightforward consequences: better memory should be linked to increased correct responding, whether measured in reference to the volume of studied information (the IBA measure) or to the volume of output information (the OBA measure). However, the consequences of changes in metacognitive processes for memory performance are less straightforward. Broadly speaking, people can modify performance by varying the criterial value of confidence, which is then captured by IBA and OBA measures in different ways. If people want to increase the quantity of correct information provided in their memory reports they can lower the criterion, ensuring that more candidate responses achieve or exceed this criterion. This should generally result in an increase in the IBA measure. However, because the ability to distinguish between correct and incorrect candidate responses is almost always going to be less than perfect, lowering the criterion can also result in volunteering some incorrect candidate responses. In fact, the more candidate responses are volunteered, the poorer the quality of these additionally volunteered responses should normally be, leading to a reduction in the OBA measure. Consequently, the IBA and OBA measures are subjected to a trade-off: an increase in the quantity obtained by lowering report criterion should generally be accompanied by a reduction in the quality and, similarly, an increase in the quality obtained by adopting a more stringent criterion should generally be accompanied by a reduction in the quantity of correct answers volunteered in a memory report.

Currently, little is known about how auditory distraction impacts upon metacognitive regulation of memory responses as captured by the Koriat and Goldsmith (1996) framework. The majority of studies on auditory distraction have used either free or serial recall tests which allow participants to withhold answers and respond "don't know." Such tests do not allow for disentangling memory and metacognitive effects of distraction because omissions from a memory report can reflect either a failure to access an appropriate memory trace or a change in metacognitive processing in one or more ways. For example, participants may become less confident of their candidate responses, so that fewer of them pass the report criterion. Alternatively, participants may become more cautious and adopt a more stringent report criterion (see **Figure 1**). To assess any presumed metacognitive component of distraction it is first necessary to present participants with a test (such as recognition) in which responding is commonly forced, not allowing participants to respond "don't know." Whilst this is comparatively rare in studies of auditory distraction, a subset of studies have employed such recognition memory tests. For example, Beaman and Jones (1997) investigated the effects of auditory distraction (sequences of non-sense words which participants were asked to ignore played over headphones) on a two-alternative forced-choice (2AFC) recognition test and found reliable impairment in recognition performance in the distraction condition (see also LeCompte, 1994; Stokes and Arnell, 2012). Since performance in forced recognition tests is not dependent on metacognitive processes of response withholding, this result confirms that auditory distraction impairs memory access directly.

The outstanding question then remains whether impairment to memory by auditory distraction is also accompanied by changes in metacognitive processes, or whether the distraction is limited to memory. For example, do people try to compensate for the impairment caused by distraction? It is possible that knowing that distraction impairs memory access, participants could change their report criterion in order to compensate for distraction and volunteer responses held with lower confidence, thus increasing the quantity of output. Indeed, a recent study by Perfect et al. (2011) examined the effects of distraction at retrieval and eye-closure (as a strategic response) on memory for actions and found that distraction did not reduce correct responding but instead increased the number of incorrect responses (an effect partially mitigated by eye closure). As noted by Perfect et al. (2011) such a pattern of results is most easily explained if distraction impairs memory and participants react to this impairment by adopting a more liberal report criterion, thus volunteering candidate responses held with lower confidence. In other words, participants in this study could strive to increase the IBA measure of memory performance, sacrificing the OBA measure in the process.

It should be also noted, however, that results obtained by Perfect et al. (2011) are atypical for the auditory distraction of the type briefly reviewed here, which more usually reduces the number of correct responses volunteered. This is particularly noticeable in free recall where the difference between "irrelevant speech" and quiet conditions is often evident only in the number of correct items volunteered (where there are typically few or no incorrect items in the recall protocol – the exception being when the irrelevant speech is semantically related to the to-be-recalled items and intrusions from the speech into the recall protocol then become relatively common; see Beaman, 2004; Beaman et al., 2013). This common result may suggest that participants typically do not become more liberal in their reporting strategies under distraction. Such a conclusion may, however, be premature. If distraction impairs memory, it may also impair the resolution of metacognitive monitoring, that is, people's ability to distinguish between their correct and incorrect candidate responses.

As described by Koriat and Goldsmith (1996), the ability to regulate memory performance, crucially depends on the resolution of metacognitive monitoring. The worse people are in distinguishing between correct and incorrect candidate responses, the less efficient their attempts to increase IBA will be. When participants decide to volunteer information held with lower confidence but resolution of their monitoring is poor, a substantial proportion of additionally volunteered responses will be incorrect, exerting little influence on IBA while at the same time undermining the OBA measure of memory performance. If auditory distraction were to impair the resolution of metacognitive monitoring at retrieval, then this could render any participants' attempts to increase the quantity of correct information in a memory report futile. Worse still, it could degrade their memory performance further by increasing the rate of intrusions. However, the extent to which resolution of metacognitive monitoring is affected by auditory distraction is currently not known.

The present study was designed to examine the effects of auditory distraction on both memory and metacognitive monitoring and control of retrieval. To this purpose, we used a procedure in which participants studied and were tested on pairs of unrelated words, with both study and test phases performed either in silence or under conditions of auditory distraction. The tests we used were 2AFC recognition tests, in which participants were asked to discriminate between a target pair and a foil pair (the types of targets and distracters used in the study are described later). Crucially, the recognition tests were specifically designed to assess both memory and metacognitive processes. Each trial of the test consisted of three separate steps (see Hanczakowski et al., 2013, for this type of a testing procedure). In an initial free-report step, participants were instructed to preserve the quality of their reports and to endorse one of the alternatives only if they were sure it was correct, while responding "don't know" if they were not sure. In the subsequent forced-report step, the "don't know" option was no longer available and participants were asked to endorse one of the alternatives even if it required guessing. Finally, in the third step, participants were asked to provide a confidence judgment regarding the accuracy of a decision they made during forced-report.

This procedure allows for describing participants' behavior in terms of the concepts developed in the Koriat and Goldsmith (1996) framework. The data from the initial free-report step allows for examining which of the candidate responses are volunteered. In conjunction with confidence judgments obtained for volunteered and withheld responses, this gives a basis upon which to assess the report criterion participants adopt in various conditions (e.g., under distraction). The forced-report test meanwhile serves as a relatively pure measure of the accuracy of direct memory access. Finally, the confidence judgments collected for responses provided in the forced-report step allow for examining the resolution of metacognitive monitoring, i.e., participants' ability to distinguish between their correct and incorrect candidate responses. This framework was employed to assess the impact of auditory distraction on memory and metacognitive processes. Specifically, we were interested: (1) whether distraction impairs memory access, as assessed in the forced-report test (a direct effect of distraction on cognition), (2) whether distraction impairs the resolution of metacognitive monitoring (an effect of distraction on a metacognitive process), (3) whether participants modify their report criterion under distraction (metacognition thereby having a modifying effect on the observed impact of distraction), and (4) how any possible changes in memory and metacognitive processes caused by distraction are reflected in the IBA and OBA measures of memory performance.

Apart from manipulating the presence of distraction at study and test, we also manipulated the nature of the recognition test. The manipulation of the type of test was introduced to examine the impact of auditory distraction on memory and metacognition under testing conditions varying in the contribution of controlled retrieval processes required. A recent investigation of auditory distraction revealed that negative effects of distraction on recognition performance were confined to conditions that require controlled retrieval, such as retrieval of contextual details, and may not be revealed in simple old/new judgments that can be made based on familiarity (Wais and Gazzaley, 2011). In our study, each list of pairs of words participants studied was followed by three separate tests, each using one third of the studied pairs as a source of targets and each presented in the three-step format described above. The first two tests were a 2AFC *associative* recognition test and a *simple* 2AFC recognition test. In the 2AFC associative recognition test foils were pairs composed of two previously studied words recombined to create a novel pair. It was not possible to succeed in this test by identifying one or both of the words as unfamiliar (as both had previously been encountered in the experimental context). Instead, participants needed to recollect which pairs had previously appeared in which combination. In the simple 2AFC recognition test targets were previously studied pairs and foils were always composed of two novel words. In this test, participants could succeed if they if they recognized the target (successful identification of the target) or if they identified either or both of the words as unfamiliar (successful rejection of a foil). The results obtained by Wais and Gazzaley (2011) lead to the prediction that the effects of auditory distraction should occur in the associative test, which relies on recollection, but not in the simple test, which can be completed with the use of familiarity.

It is important to note that, although simple recognition can be completed with the use of familiarity, recollection may still contribute to performance because reinstating an intact study pair at test may cue the pairwise association established between words at study (Cohn and Moscovitch, 2007). To provide a stronger test of the idea that the effects of auditory distraction are confined to recollection, we included a third type of test. The third test was a *recombined* 2AFC recognition test in which foils were again composed of two novel words (as in the simple test) but targets were pairs composed of recombined words, which were words included at study in different pairs. In this recombined test participants were asked to endorse pairs composed of two studied words, regardless of whether these pairs had originally appeared together. Because the original word–word association that could serve as a memory cue is not reinstated at test for the recombined pairs, the contribution of recollection to performance in this test should be further reduced. Thus, if auditory distraction impacts upon recollection only, it should have minimal impact upon this recombined test. A graphical example of the testing procedure is given in **Figure 2**.

MATERIALS AND METHODS

PARTICIPANTS

Forty-two undergraduates from Cardiff University (mean age = 21.66, range 18–40, 5 males) participated for course credit or small monetary compensation.

MATERIALS AND DESIGN

We chose 560 4- to 8-letter words from the MRC Psycholinguistic database (Coltheart, 1981), out of which 224 were used as a source of novel foils in recognition tests. These were paired to create 112 pairs to be included in four simple recognition tests and four recombined recognition tests. The remaining 336 words were

STUDY: 42 pairs of (unrelated) words

e.g., A-B, C-D, E-F

↓

TEST: 14 pairs per condition

Simple 2-AFC Recognition (Item Recollection or Item Familiarity)

e.g., TARGET: A-B FOIL: Y-Z

Associative 2-AFC Recognition (Item Recollection Only)

e.g., TARGET: A-B FOIL: C-F

Recombined 2-AFC Recognition (Item Familiarity Only)

e.g., TARGET: A-D FOIL: Y-Z

All tests conducted using:

1. Free Report (including a "don't know" option)
2. Forced Report (no "don't know" option)
3. Confidence Assignment to Forced Report

All participants experienced 2 x quiet control and 2 x speech distraction conditions for each test type (simple, associative, recombined)

FIGURE 2 | Representation of the experimental design.

randomly paired to create the 168 pairs presented at study. These study pairs were assigned to four different lists of 42 pairs. Each participant studied all four lists of pairs, two in the distraction condition and two in the quiet condition. The assignment of a list to condition was counterbalanced across participants. Pairs of words were presented across the center of a computer screen in 30 point size Times New Roman font.

The pairs in each list were further divided into three sets of 14 pairs each, which were used in three separate recognition tests following each list. In the simple recognition tests, studied pairs were presented alongside foil pairs created from two novel, previously unseen, words. In the associative recognition tests, studied pairs were presented alongside foil pairs created by presenting previously seen words in a new combination. Words for these new combinations were taken from the set of pairs that were used as targets in the same test. For example, if the pairs SLEEP–DAIRY and TABLE–CHURCH had previously been presented, a foil might be SLEEP–CHURCH or TABLE–DAIRY. Thus, in the associative recognition test each studied word was presented twice: once in a target pair and once in a foil pair (see **Figure 2**). In the recombined tests, recombined pairs (e.g., SLEEP–CHURCH) were presented along foil pairs created from two novel, previously unseen, words. The assignment of pairs to the type of test was counterbalanced across participants.

The study conformed to a 2 (distraction condition: silent vs. auditory distraction) × 3 (type of test: simple, associative, recombined recognition) within-participants design. Distraction was manipulated between lists, whereas type of test was manipulated within lists.

Auditory distraction was created by recording words from 18 different semantic categories (Yoon et al., 2004). 15 words, non-overlapping with words presented in the study lists, were taken from each semantic category. The words were spoken in female voice and were recorded at 16- bit resolution and a sampling rate of 44 KHz. The recorded words were combined into two continuous streams of speech, with individual words spoken at the approximate rate of 1 per 750 ms. One of these streams was used for each of the two lists studied and tested in the distraction condition.

PROCEDURE

Participants studied four lists of pairs, each followed by three recognition tests. The order in which the lists were presented and the order of the pairs within each list was random for each participant. In the study phase, each pair was presented individually for 1500 ms, with 500 ms interval between pairs. Three recognition tests immediately followed the study phase for a given list. Each recognition test (simple, associative, recombined) was preceded by specific instructions, explaining to participants what constituted a target and what constituted a foil in the test. The procedure for all tests consisted of three steps, always administered in the same order. First, target and foil pairs were presented with numbers "1" and "2" (randomly chosen for targets and foils) and a "don't know" option below each pair. In this free-report step, participants were asked to maximize accuracy and thus indicate a target (by pressing "1" or "2") only when they were sure which pair is a target, and to respond "don't know," by pressing the spacebar, otherwise. Immediately after the response, the pairs were presented again, this time without the "don't know" option and participants were again asked to indicate which pair they thought they recognized. Finally, the screen was cleared and participants were asked to type in a confidence judgment on a 50 ("guess")–100 ("sure") % scale that their response in the forced-report step was correct. The time for responding in all three steps was not limited.

Auditory distraction was played over the noise-canceling headphones during study and test for two lists (the remaining two were studied and tested in silence). Auditory distraction started with the onset of the first study pair in each list and also with the first test pair in each of the three recognition tests. It was however, switched off when participants were reading instructions for each of the tests.

Participants took about 30 min to complete the procedure.

RESULTS

We organize the result section according to the questions posed in Introduction and referring to (1) memory, (2) resolution of metacognitive monitoring, (3) report criterion, and (4) the IBA and OBA measures of performance. To further disentangle the memory and metamemory effects of distraction on IBA and OBA measures, we also analyze gains of using the "don't know" option in terms of quality of volunteered responses and losses in terms of quantity of volunteered correct responses. The descriptive statistics can be found in **Table 1**.

MEMORY

The recognition tests used in the present study were 2AFC tests and thus recognition hit rates in these tests serve as a measure of recognition discrimination. We analyzed hit rates in forced-report recognition tests, which did not allow for withholding responses and thus remained unaffected by any effects distraction could have on metacognitive monitoring and control of retrieval. For completeness, in this and later analyses both partial $\eta^2$and η^2 are reported as effect sizes. Partial η^2 is arguably a more appropriate effect-size measure for repeated measures designs because error due to the participant is always included in the denominator when calculating η^2 (hence partial η^2 will give a larger effect size estimate than η^2 for such designs), however, η^2 is more readily transformed for purposes of meta-analysis and other comparisons across studies. A 2 (distraction: present vs. absent) × 3 (type of test: simple, associative, recombined) repeated measures analysis of variance (ANOVA) on hit rates in forced-report recognition yielded a significant main effect of distraction, $F(1,41) = 13.85$, $MSE = 0.01$, $p < 0.001$, $\eta_p^2 = 0.25$, $\eta^2 = 0.15$, by which performance was better when distraction was absent in the quiet condition than when distraction was present. A main effect of test was also significant, $F(2,82) = 13.18$, $MSE = 0.02$, $p < 0.001$, $\eta_p^2 = 0.24$, $\eta^2 = 0.05$. This effect arose because, collapsing across distraction conditions, recognition performance was better in the recombined recognition test than in the associative recognition test, $t(41) = 2.59$, $SE = 0.02$, $p = 0.01$, and still better in the simple recognition than in the recombined recognition test, $t(41) = 2.53$, $SE = 0.02$, $p = 0.02$. The interaction of distraction and type of test was not significant, $F < 1$, indicating that distraction disrupted forced responding hit-rates on all types of tests to a similar extent.

Altogether, these results show that auditory distraction negatively affects memory processes, which finds its reflection in impaired memory performance on tests in which participants cannot withhold answers. In this, our results support the earlier finding documenting distraction effects in forced-report tests (e.g., Beaman and Jones, 1997). However, these results do not support the hypothesis that distraction is more harmful to performance on tests based on recollection than tests based on familiarity (see Wais and Gazzaley, 2011). We assumed that performance in the simple recognition test could rely on both familiarity and recollection whereas performance in associative recognition would rely mostly on recollection and performance in recombined recognition would rely mostly on familiarity. The pattern of differences in the level of performance seems at least consistent with these assumptions, with performance in simple recognition (supported by two processes) reliably higher than performance in the remaining two tests (supported by one process). Despite these differences in performance, however, distraction had a similar disruptive effect on all these tests. We return to this observation in the Discussion.

RESOLUTION OF METACOGNITIVE MONITORING

We turn now to the resolution of metacognitive monitoring, which is participants' ability to distinguish between their own correct and incorrect candidate responses[1]. Resolution is assessed by examining the relationship between confidence judgments

[1]Resolution is one aspect of the accuracy of metacognitive monitoring. The other aspect is referred to as calibration. Whereas resolution computed based on confidence judgments captures the degree to which correct candidate responses receive higher judgments than incorrect responses, calibration measures capture the degree to which mean of confidence judgments correspond to the mean memory performance. Calibration scores are usually interpreted in terms of realism of metacognitive monitoring: when mean confidence judgments are lower than memory performance participants are said to be underconfident and when mean confidence judgments are higher than memory performance participants are said

Table 1 | Table showing mean recognition accuracy (hit rate) in the forced-report tests, resolution of metacognitive monitoring (measured by area under the curve, *AUC*), report criterion adopted in free-report tests (measured by the P_{rc} measure), output-bound accuracy in the free-report tests (OBA), and input-bound accuracy in the free-report tests (IBA).

	Distraction			Quiet		
	Simple recognition	**Associative recognition**	**Recombined recognition**	**Simple recognition**	**Associative recognition**	**Recombined recognition**
Forced-report accuracy	0.78 (0.02)	0.69 (0.02)	0.74 (0.02)	0.83 (0.02)	0.73 (0.03)	0.79 (0.02)
AUC	0.73 (0.02)	0.67 (0.03)	0.66 (0.03)	0.78 (0.02)	0.68 (0.02)	0.71 (0.03)
P_{rc}	66.97 (2.50)	65.26 (2.31)	68.03 (2.65)	66.32 (2.56)	65.53 (2.14)	67.11 (2.52)
OBA	0.90 (0.02)	0.80 (0.03)	0.83 (0.02)	0.92 (0.02)	0.81 (0.03)	0.87 (0.02)
IBA	0.49 (0.03)	0.47 (0.03)	0.44 (0.04)	0.59 (0.03)	0.53 (0.03)	0.53 (0.03)
Gains in OBA	0.12 (0.02)	0.10 (0.02)	0.08 (0.01)	0.09 (0.01)	0.07 (0.01)	0.08 (0.01)
Losses in IBA	0.29 (0.02)	0.22 (0.02)	0.30 (0.03)	0.24 (0.03)	0.20 (0.02)	0.25 (0.02)
Mean confidence	77.12 (1.79)	77.19 (1.69)	71.52 (1.91)	80.70 (1.68)	80.01 (1.73)	77.14 (1.81)
Proportion "don't know"	0.38 (0.06)	0.35 (0.05)	0.42 (0.07)	0.30 (0.05)	0.29 (0.04)	0.34 (0.05)

Gains in OBA between forced- and free-report tests, losses in IBA between forced- and free-report tests, confidence judgments provided for correct forced-report recognition decisions and "don't know" responses for answers correct on the forced-report tests are all proportion measures. Standard errors of the means are given in parentheses.

given to responses in forced-report test and correctness of these responses, under the assumption that participants' metacognitive monitoring is more accurate if they are more confident in their correct responses and less confident in their incorrect responses. Traditionally, gamma correlations have been used to assess this relationship by researchers interested in metacognition (e.g., Koriat and Goldsmith, 1996) although other measures of calibration and resolution (e.g., over/under confidence statistic, point bi-serial, resolution and slope correlation) are available and, in particular, have been used more extensively by researchers interested in the relationship between eyewitness confidence and accuracy (e.g., Juslin et al., 1996; Olsson et al., 1998; Brewer, 2006; Brewer and Wells, 2006; Krug, 2007; Sauer et al., 2010). Recent work in the area of metacognition has also revealed that other measures – those based on signal detection theory – better serve to reveal the accuracy-confidence relationship in these judgments also (Masson and Rotello, 2009; see also Higham, 2002, 2007). Accordingly, we used a non-parametric measure of area under the curve (*AUC*) to assess resolution of metacognitive monitoring as expressed in confidence judgments[2]. A 2 (distraction) × 3 (type of test) ANOVA on the *AUC* measure yielded a significant main effect of distraction, $F(1,36) = 4.13$, $\text{MSE} = 0.02$, $p = 0.049$, $\eta_p^2 = 0.10$, $\eta^2 = 0.02$, with lower resolution in the presence of distraction. A main effect of type of test was also significant, $F(2,72) = 8.93$, $\text{MSE} = 0.01$, $p < 0.001$, $\eta_p^2 = 0.20$, $\eta^2 = 0.08$. This effect emerged because, collapsed across distraction conditions, resolution was better in the simple recognition tests as compared to both associative recognition, $t(36) = 4.14$, $SE = 0.02$, $p < 0.002$, and recombined recognition, $t(36) = 3.31$, $SE = 0.02$, $p = 0.002$, while the resolution in the latter tests did not differ, $t < 1$. The interaction of distraction and type of test conditions was not significant, $F < 1$. The curves from which the *AUC* measure was derived are given in **Figure 3**.

The main conclusion from the above analyses is that distraction impairs resolution of metacognitive monitoring. Thus, the distraction seems to be doubly damaging. It undermines memory performance by impairing access to memory records (as described earlier) and it also impairs participants' ability to indicate which of their responses in memory test are correct and which are incorrect.

REPORT CRITERION

The third question addressed here is whether in the presence of distraction participants adjust their report criterion. The measure of criterion placement, P_{rc}, was computed according to the methodology described by Koriat and Goldsmith (1996). Each decimal value on a confidence scale was considered as a possible placement of the report criterion by computing, first, the number of items that were assigned confidence higher than this value and which were volunteered in the free-report test (hits), and second, the number of items that were assigned confidence lower than this value and which were withheld in the free-report test (correct rejections). Hits and correct rejections were used to derive a fit ratio, which is a ratio of the sum of hits and correct rejections to the number of items in a memory test. The value with the highest

to be overconfident. However, the psychological interpretations of calibration measures have recently been questioned based on the observation that calibration scores derived from confidence judgments do not chime with the results derived from other tasks, like binary judgments or betting decisions (Hanczakowski et al., 2013; Higham et al., in press; see also Scheck and Nelson, 2005; England and Serra, 2012, for related discussion). Given the theoretical problems surrounding calibration results, we did not analyze this aspect of the accuracy of metacognitive monitoring in the present study.

[2]The degrees of freedom in this analysis differ from other analyses presented here because the *AUC* measure in at least one of the condition could not be computed for five participants, who had no incorrect responses in some conditions. These participants were excluded from this analysis.

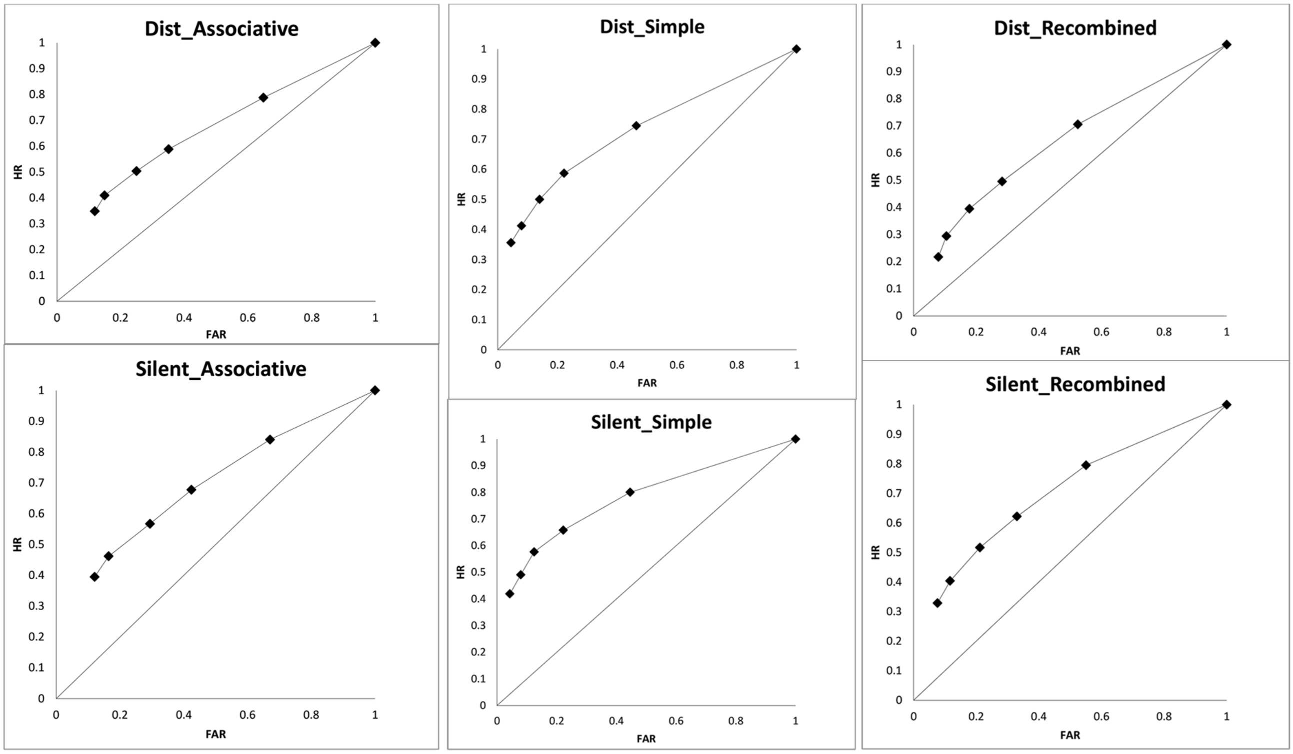

FIGURE 3 | Hit rates (HR) plotted against false alarm rates (FAR) for distraction (Dist) and silent control conditions on the associative, simple, and recombined testing conditions.

fit ratio was chosen as the placement of the report criterion and whenever an interval of values was characterized by the same fit ratio, the high boundary of this interval was chosen. This procedure of deriving the P_{rc} measure was followed in all six condition of the study. Reduced degrees of freedom for the analyses of P_{rc} reflect the fact that some participants either volunteered or withheld all answers in the free-report test in at least one of the conditions, precluding the calculation of P_{rc}. This measure was analyzed with a 2 (distraction) × 3 (type of test) ANOVA, which failed to reveal any significant effects, $F(2,74) = 1.13$, MSE = 79.66, $p = 0.33$, for the main effect of test, and Fs < 1, for the main effect of distraction and the interaction. These results indicate that the level of confidence required by participants to volunteer an answer in the free-report test was independent of the lack of distraction and the type of test.

IBA AND OBA MEASURES OF PERFORMANCE

Finally, we examined the IBA and OBA measures of memory performance in the free-report test[3]. For the OBA measure of performance in free-report tests, a 2 (distraction) × 3 (type of test) ANOVA yielded a significant main of type of test, $F(2,80) = 15.87$, MSE = 0.02, $p < 0.001$, $\eta_p^2 = 0.28$, $\eta^2 = 0.19$, which exactly paralleled the effect observed for forced-report accuracy: better performance for the recombined test than for the associative test, $t(40) = 2.33$, $SE = 0.02$, $p = 0.02$, and still better performance for the simple (vs. recombined) test, $t(40) = 3.02$, $SE = 0.02$, $p = 0.004$. The main effect of distraction was not significant, $F(1,40) = 3.22$, MSE = 0.01, $p = 0.08$. The same 2 (distraction) × 3 (type of test) ANOVA on the IBA measure yielded a significant main effect of distraction, $F(1,41) = 27.30$, MSE = 0.02, $p < 0.001$, $\eta_p^2 = 0.40$, $\eta^2 = 0.12$, showing that IBA was worse under distraction. A main effect of type of test came close to significance, $F(2,82) = 3.06$, MSE = 0.02, $p = 0.052$, $\eta_p^2 = 0.07$, $\eta^2 = 0.03$. This arose because IBA was higher in simple recognition than in associative recognition, a result which also just missed significance, $t(41) = 1.89$, SE = 0.02, $p = 0.07$, and higher also in simple recognition than in recombined recognition, $t(41) = 2.60$, SE = 0.02, $p = 0.01$[4]. Altogether, these results largely track the effects obtained with forced-report accuracy and, most importantly, indicate that participants' performance, at least if indexed by the IBA measure, is impaired under distraction when participants can respond "don't know" in a memory test.

[3]One participant was removed from all analyses involving the OBA measure because this person responded "don't know" to all questions in one of the conditions, precluding the calculation of the OBA measure.

[4]According to the yes/no logic of significance testing, these results should be treated with caution as there is an enhanced possibility of false positives when reporting such results after a null main effect. However, it is of interest to see how the data break down in cases (such as this) which so narrowly fall short of reaching conventional significance and we do not base any strong theoretical claims on these particular outcomes.

GAINS AND LOSSES FROM USING THE "DON'T KNOW" OPTION

The fact that performance was impaired in free-report tests under distraction can be easily explained by the fact that distraction affects memory access directly, as revealed in the forced-report steps. Interest remains, however, in how metamemory processes contribute to the effects observed in the OBA and IBA measures. To examine this issue, we focused on changes in performance indices between forced- and free-report tests. Koriat and Goldsmith (1996) describe how allowing participants to respond "don't know" should lead to participants screening out candidate responses they are not sure about, which in turn should generally lead to an increase in the quality of output at the cost to the quantity (see also **Figure 1**). The question addressed in the next set of analyses is whether the increases in quality and reductions in quantity between forced- and free-report tests were influenced by the distraction condition.

First, we calculated increases in quality brought about by exercising control over reporting in free-report tests. For each participant, we subtracted his or her forced-report accuracy from the OBA measure in order to calculate the gains achieved by withholding answers. For this measure, higher scores indicate a larger increase in the quality of output between forced- and free-report tests. The analysis of gains of exercising the "don't know" option with a 2 (distraction) × 3 (type of test) ANOVA revealed no significant main effect of distraction, albeit a main effect that once again came close to conventional significance, $F(1,40) = 3.44$, $MSE = 0.01$, $p = 0.07$, $\eta_p^2 = 0.079$, $\eta^2 = 0.02$. This arose because participants' quality of output increased more from forced- to free-report tests when distraction was present. Although this analysis comes close to suggesting larger gains from exercising the "don't know" option under distraction, the compared conditions differ also in the forced-report recognition performance, which was lower under distraction. Any difference in gains may thus be simply due to the fact that more correct responses are to be gained by using the "don't know" option in the distraction condition. To verify if this is indeed the case, we collapsed across type of test conditions (which did not interact with distraction in the initial analysis) and performed an additional analysis of covariance which controlled for the difference in forced-report recognition performance when comparing gains between two distraction conditions. With the difference in forced-report recognition performance as a covariate, the difference in gains between distraction and silent conditions fell well short of conventional significance, $F < 1$. It thus appears that although participants gain more in terms of quality when they use the "don't know" option under distraction, this effect can be accounted for simply by the greater potential for gain given the lower baseline rather than any more fundamental difference in the effectiveness of metacognitive processes.

To construct the measure of the reduction in the quantity of output, we subtracted the IBA measure from forced-report accuracy. For this measure, higher scores mean that more correct responses were lost from forced- to free-report test. The analysis of losses from exercising the "don't know" option with a 2 (distraction) × 3 (type of test) ANOVA revealed a significant main effect of type of test, $F(2,82) = 12.37$, $MSE = 0.02$, $p < 0.001$, $\eta_p^2 = 0.23$, $\eta^2 = 0.11$, which arose because losses were reliably lower in the associative recognition test, than in both simple recognition, $t(41) = 3.87$, $SE = 0.01$, $p < 0.001$, and recombined tests, $t(41) = 5.13$, $SE = 0.01$, $p < 0.001$. Losses for the latter two tests did not differ from each other, $t < 1$. More importantly, a significant main effect of distraction was revealed, $F(1,41) = 9.74$, $MSE = 0.01$, $p = 0.003$, $\eta_p^2 = 0.19$, $\eta^2 = 0.05$, which points to higher losses from exercising the "don't know" option in the presence (vs. absence) of distraction. The interaction was not significant, $F < 1$. We conducted a similar covariance analysis as before to account for the difference in the forced-report recognition performance between distraction and silent conditions. Collapsing across type of test conditions, the analysis with the difference in forced-report performance between silent and distraction conditions as a covariate still revealed a reliable difference between distraction and silent conditions in terms of losses, $F(1,40) = 10.34$, $MSE = 0.003$, $p = 0.003$, $\eta_p^2 = 0.21$, $\eta^2 = 0.20$. Thus, in contrast to the analysis of gains, greater losses in the quantity of output in the distraction condition were not due to differences in the forced-report recognition performance between silent and distraction conditions.

The analyses of gains and losses arising from exercising the "don't know" option revealed that allowing the "don't know" response in a memory test under distraction bears important consequences for the final performance. On the one hand, participants in the present study initially appeared to gain more in terms of quality in the distraction compared to the silent condition. This effect, however, did not stem from any differences in metacognitive processes but simply from the fact that with lower memory performance participants had more to gain under auditory distraction. More cogently, the presence of distraction caused also greater losses in term of quantity of correct responses when participants were allowed to respond "don't know." This effect was independent of differences in forced-report recognition in silent and distraction condition and thus must reflect a metacognitive effect.

The effect of greater losses of correct responses under distraction might, in principle, be the result of two different mechanisms. One such mechanism is reduced relative accuracy of metacognitive monitoring under distraction. When participants are worse in assessing which their candidate responses are correct and incorrect, using the "don't know" option can lead to withholding of more correct responses. To assess this account, we performed an additional covariance analysis in which differences in the *AUC* measure between the distraction and silent conditions (again collapsed across different tests) served as a covariate for the analysis of losses[5]. This analysis again resulted in a reliable differences in losses between the distraction and silent conditions, $F(1,35) = 4.79$, $MSE = 0.003$, $p = 0.035$, $\eta_p^2 = 0.12$, $\eta^2 = 0.11$, suggesting that differences in the accuracy of metacognitive monitoring cannot account for the observed pattern of losses.

A second mechanism that can account for greater losses under distraction is reduced confidence in correct responses. If participants are overall less confident in their correct responses under distraction, then fewer of these correct candidate responses will

[5]Five participants were excluded from this analysis due to incomplete set of *AUC* results.

pass the rigid response criterion (see the earlier analysis of the P_{rc} measure). To test this hypothesis we analyzed confidence for answers that were correct on the forced-report recognition tests. The analysis of confidence with a 2 (distraction) × 3 (type of test) ANOVA yielded a significant main effect of test, $F(2,82) = 12.45$, MSE = 44.21, $p < 0.001$, $\eta_p^2 = 0.233$, $\eta^2 = 0.114$, which arose because confidence in correct responses was lower in the recombined test than in either the simple recognition test, $t(41) = 4.33$, SE = 1.06, $p < 0.001$, or the associative recognition test, $t(41) = 3.87$, SE = 1.10, $p < 0.001$, which did not differ from each other, $t < 1$. More importantly, the main effect of distraction was also significant, $F(1,41) = 26.97$, MSE = 37.50, $p < 0.001$, $\eta_p^2 = 0.397$, $\eta^2 = 0.105$, confirming that participants were less confident in their correct responses under distraction. The interaction was not significant, $F(2,82) = 1.58$, MSE = 28.01, $p = 0.21$. To ensure that lowered confidence in correct responses under distraction found its reflection in the pattern of response volunteering, we also analyzed the rates of "don't know" responding for responses that were correct on the forced-report recognition test. A 2 (distraction) × 3 (type of test) ANOVA yielded a significant main effect of type of test, $F(2,82) = 4.99$, MSE = 0.017, $p = 0.009$, $\eta_p^2 = 0.108$, $\eta^2 = 0.045$, which arose because participants more often responded "don't know" for questions scored as correct in the forced-report recombined test than in either the forced-report simple recognition test, $t(41) = 2.06$, SE = 0.02, $p = 0.046$, or the forced-report associative recognition test, $t(41) = 2.88$, SE = 0.02, $p = 0.006$, which in turn did not differ, $t(41) = 1.14$, SE = 0.02, $p = 0.26$. Again, the main effect of distraction was significant, $F(1, 41) = 15.94$, MSE = 0.02, $p < 0.001$, $\eta_p^2 = 0.280$, $\eta^2 = 0.09$, with fewer responses that were correct on the forced-report test volunteered under distraction[6]. These analyses indicate that distraction affects performance when a "don't know" response is allowed by reducing confidence in correct candidate responses, which leads to fewer correct responses being volunteered. Overall, reduced confidence under distraction is related to greater response withholding, this constitutes a metacognitive mechanism by which distraction exerts influence over memory performance.

DISCUSSION

The present study was designed to investigate memory and metacognitive processes under auditory distraction. The main results can be summarized in few points. First, distraction consistently impaired memory as revealed by forced-report recognition accuracy. Thus, there was an effect of distraction on cognition under forced-choice conditions. Second, distraction affected metacognitive monitoring of retrieval by impairing participants' ability to distinguish between their own correct and incorrect candidate responses (as reflected in the confidence measures). Thus, there was also an effect of distraction on metacognitive outcomes. Third, participants did not try to strategically compensate for the loss in the quantity of output under distraction by lowering their report criterion. Instead, participants used the same report criterion in all conditions of our study. Fourth, distraction affected both benefits and costs of using the "don't know" option. Larger gains in accuracy under distraction stemmed from the fact that, with poorer memory in the presence of distraction, participants had more to gain by withholding responses. However, losses in terms of quantity of correct responses were also larger under distraction, stemming from the fact that participants were generally less confident in their correct responses when distraction was present, leading to more prevalent withholding of these correct responses. Thus, there appeared to be an impact of some metacognitive factors (confidence) but not on others (report criterion or threshold) on the distraction observed. A limitation of the study is that, because distraction was present at both encoding and retrieval we are unable to tease apart potentially different impacts on metacognitive processes at these stages. The literature on auditory distraction shows that some distractors (so-called "changing-state" irrelevant sound distractors, Jones et al., 1992; Jones and Macken, 1993) operating on short-term serial order episodic memory (Beaman and Jones, 1997) are equipotent at encoding and retrieval (Miles et al., 1991) whereas semantic auditory distractors operating on semantic memory lose potency to induce false positive errors when presented only during a retention period (Marsh et al., 2008). Thus, this particular area is open to further research in which both the types of distraction and the period of distraction are varied.

The fact that auditory distraction is harmful for visual memory performance is hardly surprising given numerous studies which already document such detrimental effects. However, the present study allows for a clearer picture of how impairment in performance is caused by distraction affecting both memory access directly, and metacognitive processes responsible for translating retrieved information into free-report performance. The study was built on the assumption borrowed from the framework by Koriat and Goldsmith (1996) that performance in a test allowing for "don't know" responses is dependent on both memory and metacognitive processes. Here we demonstrated that auditory distraction affects both memory and metacognition, which jointly determine performance in free-report tests.

In our study we included a forced-report test in which withholding responses was not possible, thus minimizing the role of metacognitive processes. The fact that distraction impaired forced-report responding provides further support for previous research using this format of testing (e.g., LeCompte, 1994; Beaman and Jones, 1997) in showing that auditory distraction has a negative impact on core memory processes. Importantly, we used three different types of recognition test, in which performance was at least partially supported by distinct memory processes of familiarity and recollection and yet the effects of auditory distraction were exactly the same in all these tests. This observation points to a general disruptive effects of distraction upon various memory processes regardless of the relative contribution of recollection and familiarity in these tests. This is surprising given the differential impact of auditory distraction upon other memory tasks – notably

[6]Although incorrect responses do not contribute to the pattern of losses which is discussed here, for completeness we separately analyzed confidence and the rate of "don't know" responses when an incorrect response was given in the forced-report test. Since quite a few participants had no incorrect forced-report responses in one or more cells of the full design, for the present analyses we collapsed across the type of test variable, which resulted in excluding two participants only. The comparisons of quiet and distraction conditions in terms of both confidence in incorrect forced-report responses (62.14 vs. 63.15) and the rate of "don't know" responses when forced-response was incorrect (0.66 vs. 0.66) were not significant, $ts < 1$.

the reliable impact upon probed or serial recall which is either absent or much reduced in a "missing item task" in which participants are required to identify which member of a well-known set was not presented at study (Beaman and Jones, 1997). Here, it seems plausible that familiarity might be used to identify missing items (by recalling all items from the set and assessing which has the lowest familiarity level) whereas recollection is necessary for probed recall. These tasks differ in other ways, however, notably the requirement to recall a pairwise, positional, or serial-order association for the probed recall task – arguably also present in the current set of 2AFC recognition tests, which is entirely absent from a missing item recall task (see also Jones and Macken, 1993; Beaman and Jones, 1998).

In this observation of generalized effects of auditory distraction by speech on memory processes, our results also stand in contrast to the recent results obtained by Wais and Gazzaley (2011), who documented the effects of distraction in a test dependent on recollection but not in the test dependent on familiarity. Various procedural differences may underlie this discrepancy but the most likely seems to be that whereas Wais and Gazzaley (2011) played distraction during retrieval only, in our study distraction was present during both encoding and retrieval. Some researchers (e.g., Neath, 2000) have argued that the effects of auditory distraction are similar to the effects of manipulations imposing cognitive load, like for example requiring participants to engage in an additional cognitive task apart from encoding and retrieval. Dual-task manipulations, when implemented at the time of a memory test, are known to affect recollection, leaving familiarity relatively intact (e.g., Gruppuso et al., 1997). By contrast, dual-task manipulations implemented at the time of encoding affect both recollection and familiarity (Yonelinas, 2001). Thus, our findings of auditory distraction effects of similar magnitude in recollection- and familiarity-based tests can be easily reconciled with findings pointing to specific recollection impairment obtained by Wais and Gazzaley (2011) if one is willing to assume that auditory distraction, in some respects, works similarly to an additional cognitive task, putting tax on attentional resources available for encoding and retrieval[7]. Pilot data from our lab support this idea, by showing an impact of auditory distraction upon pupillometric measures of cognitive effort at encoding. To conclude, it is likely that it is our design choice of presenting distraction both at encoding and at retrieval that precluded us from observing differential effects of auditory distraction on familiarity and recollection. This issue could be pursued in further studies that could factorially manipulate when distraction is presented to examine performance in recognition tests sensitive to familiarity and recollection effects.

The results documented in our study with free-report tests also reveal that effects of distraction do not end with impairing memory processes. Auditory distraction has important consequences for how accurate people are in monitoring their memory processes, as revealed by impaired resolution of confidence judgments under distraction. Even more importantly, auditory distraction modifies metacognitive control and thus shapes performance when the "don't know" option is available in a memory test. Participants seem to be aware that auditory distraction is harmful for memory as they become much less confident in their correct responses when distraction is present (see also Ellermeier and Zimmer, 1997; Beaman, 2005b). In their responding on a free-report test they strive to attain a similar level of accuracy of reported responses whether distraction is present or not, as revealed by an equal report criterion between distraction and quiet conditions. However, since participants are generally less confident, fewer correct candidate responses pass the report criterion when distraction is present. With fewer correct responses volunteered, the IBA measure of accuracy suffers. Not only is the IBA measure lower under distraction but also losses in quantity caused by using the "don't know" option are higher when distraction is present.

This last finding is important inasmuch as it testifies to metacognitive contributions to performance decrement caused by distraction in free-report tests. When free-report test are used, the IBA measure of performance is commonly interpreted as reflecting memory processes only (cf. Koriat and Goldsmith, 1996; Hanczakowski et al., 2014). This can be gleaned from paradigms using free recall, a par excellence IBA measure of performance, in which results are discussed in terms of memory, not metamemory. In respect to auditory distraction, several recent papers dealing with distraction semantically related to memoranda have revealed performance decrements in free recall tests under semantic auditory distraction (e.g., Marsh et al., 2008, 2009). What the present study underscores is that results obtained with free recall tests should be interpreted in view of distraction impacting upon both memory and metacognitive processes. It thus remains to be examined if auditory distractions semantically related to memoranda impact upon metacognitive processes, changing the pattern of confidence and "don't know" responding, and thus contributing to the overall pattern of free recall impairment.

In conclusion, the present study showed how auditory distraction affects both memory processes and metacognitive processes that influence memory reporting. In broadest terms, auditory distraction when present at both encoding and retrieval negatively impacts upon a spectrum of performance measures in memory tasks. However, a specific pattern of impairment in these measures is visible, shaped by the effects distraction has on metacognitive processes, with important roles of the overall level of confidence assigned to correct candidate responses and the ability to distinguish between one's own correct and incorrect candidate responses.

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REFERENCES

Beaman, C. P. (2004). The irrelevant sound phenomenon revisited: what role for working memory capacity? *J. Exp. Psychol. Learn. Mem. Cogn.* 30, 1106–1118. doi: 10.1037/0278-7393.30.5.1106

[7]Note, however, that there are multiple types of auditory distraction (e.g., those based around the acoustics of the distractor and those based upon the lexical and semantic status of speech) which appear to impact on different tasks differentially (Hughes and Jones, 2003; Beaman, 2005a; Jones et al., 2010). Without further investigation varying the distractor type do not know which type of distraction we (or Wais and Gazzaley, 2011) observed.

Beaman, C. P. (2005a). Auditory distraction from low-intensity noise: a review of the consequences for learning and workplace environments. *Appl. Cogn. Psychol.* 19, 1041–1064. doi: 10.1002/acp.1134

Beaman, C. P. (2005b). Irrelevant sound effects amongst younger and older adults: objective findings and subjective insights. *Eur. J. Cogn. Psychol.* 17, 241–265. doi: 10.1080/09541440440000023

Beaman, C. P., and Jones, D. M. (1997). Role of serial order in the irrelevant speech effect: tests of the changing-state hypothesis. *J. Exp. Psychol. Learn. Mem. Cogn.* 2, 459–471. doi: 10.1037/0278-7393.23.2.459

Beaman, C. P., and Jones, D. M. (1998). Irrelevant sound disrupts order information in free recall as in serial recall. *Q. J. Exp. Psychol.* 51A, 615–636. doi: 10.1080/713755774

Beaman, C. P., Hanczakowski, M., Hodgetts, H. M., Marsh, J. E., and Jones, D. M. (2013). Memory as discrimination: what distraction reveals. *Mem. Cogn.* 41, 1238–1251. doi: 10.3758/s13421-013-0327-4

Bell, R., Röer, J. P., and Buchner, A. (2013). Irrelevant speech disrupts item-context binding. *Exp. Psychol.* 60, 376–384. doi: 10.1027/1618-3169/a000212

Brewer, N. (2006). Uses and abuses of eyewitness identification confidence. *Legal Criminol. Psychol.* 11, 3–23. doi: 10.1348/135532505X79672

Brewer, N., and Wells, G. L. (2006). The confidence-accuracy relationship in eyewitness identification: effects of lineup instructions, foil similarity, and target-absent base rates. *J. Exp. Psychol. Appl.* 12, 11–30. doi: 10.1037/1076-898X.12.1.11

Broadbent, D. E. (1982). Task combination and selective intake of information. *Acta Psychol.* 50, 253–290. doi: 10.1016/0001-6918(82)90043-9

Cohn, M., and Moscovitch, M. (2007). Dissociating measures of associative memory: evidence and theoretical implications. *J. Mem. Lang.* 57, 437–454. doi: 10.1016/j.jml.2007.06.006

Coltheart, M. (1981). The MRC psycholinguistic database. *Q. J. Exp. Psychol.* 33A, 497–505. doi: 10.1080/14640748108400805

Ellermeier, W., and Zimmer, K. (1997). Individual differences in susceptibility to the 'irrelevant speech effect'. *J. Acoust. Soc. Am.* 102, 2191–2199. doi: 10.1121/1.419596

Elliott, E. M., and Cowan, N. (2005). Coherence of the irrelevant-sound effect: individual profiles of short-term memory and susceptibility to task-irrelevant materials. *Mem. Cogn.* 33, 664–675. doi: 10.3758/BF031 95333

England, B. D., and Serra, M. J. (2012). The contributions of anchoring and past-test performance to the underconfidence-with-practice effect. *Psychon. Bull. Rev.* 19, 715–722. doi: 10.3758/s13423-012-0237-7

Goldsmith, M., Pansky, A., and Koriat, A. (2014). "Metacognitive control of memory reporting," in *The SAGE Handbook of Applied Memory*, eds T. J. Perfect and D. S. Lindsay (London: Sage), 481–500. doi: 10.4135/9781446294703.n27

Gruppuso, V., Lindsay, D. S., and Kelley, C. M. (1997). The process-dissociation procedure and similarity: defining and estimating recollection and familiarity in recognition memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 23, 259–278. doi: 10.1037/0278-7393.23.2.259

Hanczakowski, M., Pasek, T., Zawadzka, K., and Mazzoni, G. (2013). Cue familiarity and 'don't know' responding in episodic memory tasks. *J. Mem. Lang.* 69, 368–383. doi: 10.1016/j.jml.2013.04.005

Hanczakowski, M., Zawadzka, K., and Coote, L. (2014). Context reinstatement in recognition: memory and beyond. *J. Mem. Lang.* 72, 85–97. doi: 10.1016/j.jml.2014.01.001

Hanczakowski, M., Zawadzka, K., Pasek, T., and Higham, P. A. (2013). Calibration of metacognitive judgments: insights from the underconfidence-with-practice effect. *J. Mem. Lang.* 69, 429–444. doi: 10.1016/j.jml.2013.05.003

Higham, P. A. (2002). Strong cues are not necessarily weak: Thomson and Tulving (1970) and the encoding specificity principle revisited. *Mem. Cogn.* 30, 67–80. doi: 10.3758/BF03195266

Higham, P. A. (2007). No special K! A signal detection framework for the strategic regulation of memory accuracy. *J. Exp. Psychol. Gen.* 136, 1–22. doi: 10.1037/0096-3445.136.1.1

Higham, P. A., Zawadzka, K., and Hanczakowski, M. (in press). "Internal mapping and its impact on measures of absolute and relative metacognitive accuracy," in *The Oxford Handbook of Metamemory*, eds J. Dunlosky and S. K. Tauber (New York: Oxford University Press).

Hughes, R. W., and Jones, D. M. (2003). Indispensible benefits and unavoidable costs of unattended sound for cognitive functioning. *Noise Health* 6, 63–76.

Jones, D. M., Hughes, R. W., and Macken, W. J. (2010). Auditory distraction and serial memory: the avoidable and the ineluctable. *Noise Health* 12, 201–209. doi: 10.4103/1463-1741.70497

Jones, D. M., and Macken, W. J. (1993). Irrelevant tones produce an irrelevant speech effect: implications for phonological coding in working memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 19, 369–381. doi: 10.1037/0278-7393.19.2.369

Jones, D. M., Madden, C., and Miles, C. (1992). Privileged access by irrelevant speech to short-term memory: the role of changing-state. *Q. J. Exp. Psychol.* 44, 645–669. doi: 10.1080/14640749208401304

Juslin, P., Olsson, N., and Winman, A. (1996). Calibration and diagnosticity of confidence in eyewitness identification: comments on what can be inferred from the low confidence-accuracy correlation. *J. Exp. Psychol. Learn. Mem. Cogn.* 22, 1304–1316. doi: 10.1037/0278-7393.22.5.1304

Koriat, A. (2007). "Metacognition and consciousness," in *The Cambridge Handbook of Consciousness*, eds P. D. Zelazo, M. Moscovitch, and E. Thompson (Cambridge, UK: Cambridge University Press), 289–325. doi: 10.1017/CBO9780511816789.012

Koriat, A., and Goldsmith, M. (1996). Monitoring and control processes in the strategic regulation of memory accuracy. *Psychol. Rev.* 103, 490–517. doi: 10.1037/0033-295X.103.3.490

Krug, K. (2007). The relationship between confidence and accuracy: current thoughts of the literature and a new area of research. *Appl. Psychol. Crim. Justice* 3, 7–41.

LeCompte, D. C. (1994). Extending the irrelevant speech effect beyond serial recall. *J. Exp. Psychol. Learn. Mem. Cogn.* 20, 1396–1408. doi: 10.1037/0278-7393.20.6.1396

Marsh, J. E., Hughes, R. W., and Jones, D. M. (2008). Auditory distraction in semantic memory: a process-based approach. *J. Mem. Lang.* 58, 682–700. doi: 10.1016/j.jml.2007.05.002

Marsh, J. E., Hughes, R. W., and Jones, D. M. (2009). Interference by process, not content, determines semantic auditory distraction. *Cognition* 110, 23–38. doi: 10.1016/j.cognition.2008.08.003

Masson, M. E. J., and Rotello, C. M. (2009). Sources of bias in the Goodman-Kruskal gamma coefficient measure of association: implications for studies of metacognitive processes. *J. Exp. Psychol. Learn. Mem. Cogn.* 35, 509–527. doi: 10.1037/a0014876

Miles, C., Jones, D. M., and Madden, C. A. (1991). Locus of the irrelevant speech effect in short-term memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 17, 578–584. doi: 10.1037/0278-7393.17.3.578

Neath, I. (2000). Modeling the effects of irrelevant speech on memory. *Psychon. Bull. Rev.* 7, 403–423. doi: 10.3758/BF03214356

Olsson, N., Juslin, P., and Winman, A. (1998). Realism of confidence in earwitness versus eyewitness identification. *J. Exp. Psychol. Appl.* 4, 101–118. doi: 10.1037/1076-898X.4.2.101

Perfect, T. J., Andrade, J., and Eagan, I. (2011). Eye closure reduces the cross-modal memory impairment caused by auditory distraction. *J. Exp. Psychol. Learn. Mem. Cogn.* 37, 1008–1013. doi: 10.1037/a0022930

Salamé, P., and Baddeley, A. D. (1982). Disruption of short-term memory by unattended speech: implications for the structure of working memory. *J. Verbal Learn. Verbal Behav.* 21, 150–164. doi: 10.1016/S0022-5371(82)90521-7

Salamé, P., and Baddeley, A. D. (1986). The unattended speech effect: perception or memory? *J. Exp. Psychol. Learn. Mem. Cogn.* 12, 525–529. doi: 10.1037/0278-7393.12.4.525

Sauer, J., Brewer, N., Zweck, T., and Weber, N. (2010). The effect of retention interval on the confidence-accuracy relationship for eyewitness identification. *Law Hum. Behav.* 34, 337–347. doi: 10.1007/s10979-009-9192-x

Scheck, P., and Nelson, T. O. (2005). Lack of pervasiveness of the underconfidence-with-practice effect: boundary conditions and an explanation via anchoring. *J. Exp. Psychol. Gen.* 134, 124–128. doi: 10.1037/0096-3445.134.1.124

Stokes, K. A., and Arnell, K. M. (2012). New considerations for the cognitive locus of impairment in the irrelevant-sound effect. *Mem. Cogn.* 40, 918–931. doi: 10.3758/s13421-012-0194-4

Thiede, K. W., and Dunlosky, J. (1999). Toward a general model of self-regulated study: an analysis of selection of items for study and self-paced study time. *J. Exp. Psychol. Learn. Mem. Cogn.* 25, 1024–1037. doi: 10.1037/0278-7393.25.4.1024

Wais, P. E., and Gazzaley, A. (2011). The impact of auditory distraction on retrieval of visual memories. *Psychon. Bull. Rev.* 18, 1090–1097. doi: 10.3758/s13423-011-0169-7

Yonelinas, A. P. (2001). Consciousness, control and confidence: the three Cs of recognition memory. *J. Exp. Psychol. Gen.* 130, 361–379. doi: 10.1037/0096-3445.130.3.361

Yoon, C., Feinberg, F., Hu, P., Gutchess, A. H., Hedden, T., Chen, H.-Y. M., et al. (2004). Category norms as a function of culture and age: comparisons of item responses to 105 categories by American and Chinese adults. *Psychol. Aging* 19, 379–393. doi: 10.1037/0882-7974.19.3.379

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Metacognition moderates the effects of distraction on cognition

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A commentary on

The effects of distraction on metacognition and metacognition on distraction: evidence from recognition memory
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The work in the Research Topic illustrates the growing interest in the effects of distraction upon cognitive performance, in particular memory. In their excellent article, Beaman et al. (2014) point out that the majority of previous work on this topic has used memory tasks that allow little opportunity for the participants to demonstrate metacognitive monitoring or control of their performance. Given the myriad demonstrations of the influences of metacognitive monitoring and control on memory performance, this is a clear omission. For example, students studying for an exam may judge their own degree of learning (monitoring) and decide whether or not to study further (control). Similarly, eyewitnesses may evaluate their confidence in their memory (monitoring) and decide whether or not to make a positive identification decision (control). The paper sets out to investigate (1) whether distraction influences metacognition, as well as memory itself and (2) whether metacognition contributes to memory impairments.

Beaman and colleagues investigate distraction in the context of Koriat and Goldsmith's (1996) memory-control framework. This framework proposes that memory output in response to a cue is the result of three steps: generation of a best candidate answer, monitoring the quality of that answer (measured by confidence), and an output decision based upon comparing the monitored quality with output goals (measured by looking at the propensity to withhold answers). By comparing performance on tasks that allow withholding of answers (free-report) with performance on tasks that do not allow such control (forced-report), Koriat and Goldsmith were able to determine the trade-off between memory quantity and memory accuracy. Beaman and colleagues examined the effects of distraction on all aspects of the framework, by looking at: (a) the number of correct answers available (reflected in forced-report measures), (b) subjective assessments of the accuracy of candidate answers (reflected in confidence measures), and (c) the threshold at which participants are willing to report an answer (reflected in free-report and confidence measures).

In line with established effects in the literature, Beaman and colleagues show that distraction impacted upon retrieval of candidate answers (e.g., Glenberg et al., 1998; Vredeveldt et al., 2011; Perfect et al., 2012; Rae and Perfect, 2014). This is reassuring, but not new. The strength of the paper lies in the examination of metacognitive components of performance, which is both novel and thorough. Beaman and colleagues found that distraction impacted upon some, but not all metacognitive measures. Under distraction, participants were less able to distinguish their correct from incorrect answers (resolution). Whilst distraction did not affect the accuracy of answers volunteered in free report, it did result in fewer correct answers being volunteered. An intriguing aspect of performance was that distraction caused people to withhold answers more often, but did not change report threshold (as measured by confidence). Further detailed analysis demonstrated that this pattern arose because distraction lowered confidence in correct answers. As a result, participants found it harder to distinguish correct from incorrect answers and said "don't know" more often, despite maintaining the same criterion for outputting an answer.

Beaman and colleagues' examination of the impact of distraction on different metacognitive indices is both elegant and informative. It opens a fruitful avenue of research for others to follow, with clear theoretical and practical relevance. Four important issues spring to mind, but others will no doubt be inspired to take a different route. The authors themselves note that one issue will be to disentangle the effects of distraction on metacognition during encoding and retrieval, because the methodology used had distraction during both phases, but only measured metacognitive indices during retrieval. Disentangling these effects would address clear applied questions, for example: does distraction impair the ability to judge the degree of learning (cf. (Banbury and Berry, 1998; Hygge et al., 2003)), or the appropriate allocation of study time?

A related issue will be to investigate the effects of distraction on metacognition when memory quality varies. Many factors can impair the quality of the memory trace, for example, distraction or low attention during encoding, or long delays between encoding and retrieval. This raises the possibility that the metacognitive changes observed by Beaman and colleagues were not due to distraction during retrieval, but were the result of having to monitor lower-quality memory traces (due to distraction during encoding). This argument mirrors exactly the debate in another domain: the accuracy of feeling-of-knowing (FOK) judgements in younger and older adults. Whilst there is general agreement that older adults' episodic FOK judgements are less accurate, some have attributed this to poor monitoring at retrieval (Souchay et al., 2007), whilst others have attributed it to poor encoding (Perfect and Stollery, 1993; Hertzog et al., 2010).

The third issue concerns the nature of distraction: the present paper uses semantically meaningful, verbal distraction that is similar to the to-be-remembered material. It is unknown to what extent other forms of distraction impair metacognitive monitoring and control. Meaningless distraction during retrieval, such as moving shapes (Perfect et al., 2012), white noise (Perfect et al., 2011), or street noise (Vredeveldt and Penrod, 2013), has been found to impact memory performance, but these studies have lacked the metacognitive approach developed here (but cf. Vredeveldt and Sauer, 2015).

The final issue that remains unexplored is the impact of distraction upon sensitivity to output goals. Beaman and colleagues encouraged participants to maximize accuracy in free report, but there was no systematic variation in rewards and penalties associated with correct and incorrect responses. Koriat and Goldsmith (1994) found that people adjust their report threshold when the penalty for error is a small financial penalty, or the loss of all accrued rewards. Distraction could affect this strategic adjustment of report threshold.

In summary, Beaman and colleagues provide a stimulating approach to the examination of effects of distraction on performance, reminding us that memory retrieval in humans is the result of a subtle interplay between basic cognitive processes and metacognitive monitoring and control of those processes. They demonstrate that metacognitive impairments resulting from distraction can impair memory performance, and they offer a broad and sophisticated array of metacognitive measures with which to explore these issues. Our hope is that this work stimulates others to follow.

REFERENCES

Banbury, S. P., and Berry, D. C. (1998). Disruption of office-related tasks by speech and office noise. *Br. J. Psychol.* 89, 499–517. doi: 10.1111/j.2044-8295.1998.tb02699.x

Beaman, C. P., Hanczakowski, M., and Jones, D. M. (2014). The effects of distraction on metacognition and metacognition on distraction: evidence from recognition memory. *Front. Psychol.* 5:439. doi: 10.3389/fpsyg.2014.00439

Glenberg, A. M., Schroeder, J. L., and Robertson, D. A. (1998). Averting the gaze disengages the environment and facilitates remembering. *Mem. Cogn.* 26, 651–658. doi: 10.3758/BF03211385

Hertzog, C., Dunlosky, J., and Sinclair, S. M. (2010). Episodic feeling-of-knowing resolution derives from the quality of original encoding. *Mem. Cogn.* 38, 771–784. doi: 10.3758/MC.38.6.771

Hygge, S., Boman, E., and Enmarker, I. (2003). The effects of road traffic noise and meaningful irrelevant speech on different memory systems. *Scand. J. Psychol.* 44, 13–21. doi: 10.1111/1467-9450.00316

Koriat, A., and Goldsmith, M. (1994). Memory in naturalistic and laboratory contexts: distinguishing the accuracy-oriented and quantity-oriented approaches to memory assessment. *J. Exp. Psychol. Gen.* 123, 297–315. doi: 10.1037/0096-3445.123.3.297

Koriat, A., and Goldsmith, M. (1996). Monitoring and control processes in the strategic regulation of memory accuracy. *Psychol. Rev.* 103, 490–517. doi: 10.1037/0033-295X.103.3.490

Perfect, T. J., Andrade, J., and Eagan, I. (2011). Eye-closure reduces the cross-modal memory impairment caused by auditory distraction. *J. Exp. Psychol. Learn. Mem. Cogn.* 37, 1008–1013. doi: 10.1037/a0022930

Perfect, T. J., Andrade, J., and Syrett, L. (2012). Environmental visual distraction during retrieval affects the quality, not the quantity, of eyewitness recall. *Appl. Cogn. Psychol.* 26, 296–300. doi: 10.1002/acp.1823

Perfect, T. J., and Stollery, B. (1993). Memory and metamemory performance in older adults: one deficit or two? *Q. J. Exp. Psychol. A* 46, 119–135.

Rae, P. J. L., and Perfect, T. J. (2014). Visual distraction during word-list retrieval does not consistently disrupt memory: no evidence for a finite cognitive resource theory. *Front. Psychol.* 5:362. doi: 10.3389/fpsyg.2014.00362

Souchay, C., Moulin, C. J. A., Clarys, D., Taconnat, L., and Isingrini, M. (2007). Diminished episodic memory awareness in older adults: evidence from feeling-of-knowing and recollection. *Conscious. Cogn.* 16, 769–784. doi: 10.1016/j.concog.2006.11.002

Vredeveldt, A., Hitch, G. J., and Baddeley, A. D. (2011). Eyeclosure helps memory by reducing cognitive load and enhancing visualisation. *Mem. Cogn.* 39, 1253–1263. doi: 10.3758/s13421-011-0098-8

Vredeveldt, A., and Penrod, S. D. (2013). Eye-closure improves memory for a witnessed event under naturalistic conditions. *Psychol. Crime Law* 19, 893–905. doi: 10.1080/1068316X.2012.700313

Vredeveldt, A., and Sauer, J. D. (2015). Effects of eye-closure on confidence-accuracy relations in eyewitness testimony. *J. Appl. Res. Mem. Cogn.* 4, 51–58. doi: 10.1016/j.jarmac.2014.12.006

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Visual distraction during word-list retrieval does not consistently disrupt memory

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Glenberg et al. (1998) reported that episodic memory is impaired by visual distraction and argued that this effect is consistent with a trade-off between internal and external attentional focus. However, their demonstration that visual distraction impairs memory for lists used 15 consecutive word-lists, with analysis only of mid-list items, and has never been replicated. Experiment 1 ($N = 37$) replicated their methodology and found the same pattern of impairment for mid-list recall, but found no evidence of impairment for other items on the lists. Experiment 2 ($N = 64$) explored whether this pattern arises because the mid-list items are poorly encoded (by manipulating presentation rate) or because of interference. Experiment 3 ($N = 36$) also looked at the role of interference whilst controlling for potential item effects. Neither study replicated the pattern seen in Experiment 1, despite reliable effects of presentation rate (Experiment 2) and interference (Experiments 2 and 3). Experiment 2 found no effect of distraction for mid-list items, but distraction did increase both correct and incorrect recall of all items suggestive of a shift in willingness to report. Experiment 3 found no effects of distraction whatsoever. Thus, there is no clear evidence that distraction consistently impairs retrieval of items from lists and therefore no consistent evidence to support the embodied cognition account used to explain the original finding.

Keywords: visual distraction, dynamic visual noise, episodic memory, word-list recall, recall error, embodied memory

INTRODUCTION

The physical environment is often distracting. Open-plan work places, for example, are replete with visual and auditory background noise: 99% of office workers responding to Banbury and Berry's (2005) survey claimed that this noise was so distracting it adversely affected concentration. Considering that it is commonplace to carry out daily tasks in distracting environments, it is not surprising that numerous researchers have investigated the effect of distraction on cognitive processes including episodic memory.

Evidence that environments are distracting to retrieval processes comes from observations of gaze aversion. When trying to remember an item from memory, people often look away from their immediate environment in order to suppress its distracting effect (Doherty-Sneddon and Phelps, 2005). For example, Glenberg et al. (1998; Experiment 1) observed that participants were increasingly likely to avert their gaze during recall the further the target memories were back in time. This suggests that as the task becomes more difficult, people spontaneously avert their gaze away from the distracting environment in order to focus attention inwardly to the task of retrieval. Although gaze aversion is also commonly seen during social interactions (Kendon, 1967) two studies suggest that it serves more of a distraction-suppression function than a social function. Glenberg et al. (1998; Experiment 3) video-taped participants whilst they sat alone in a laboratory typing answers to increasingly difficult general knowledge questions. In the absence of any social interaction the frequency of gaze aversion increased as memory task-difficulty increased. Doherty-Sneddon and Phelps (2005) found that regardless of whether the interview was conducted in person or by video-link-up, the frequency of gaze aversion was driven by the difficulty of the memory retrieval task, rather than the interview setting. In contrast to these findings, Markson and Paterson (2009; Experiment 2) found that performance on a visual-spatial imagination task was poorer when participants maintained face-to-face eye-contact with the experimenter compared to when averting their gaze by looking at a photograph of the experimenter or closing their eyes. Although the authors conclude that the benefits of gaze aversion are a result of removing the face-to-face social aspect of eye-contact, they are clear to point out that these findings are based on performance of a visual-spatial imagination task which, unlike the above two studies, does not involve memory recall.

Additional evidence of the distracting nature of the environment comes from the field of eye-witness interviews which has looked at the beneficial effects of reducing environmental distraction via instructed eye-closure (EC), and the negative effects of experimental increases in environmental distraction. Wagstaff et al. (2004; Experiment 2) asked participants to recall details of a prominent past event with their eyes open or their eyes-closed. Their participants had all watched the live television broadcast of Diana, Princess of Wales's funeral some 5 years earlier but had not watched it again since. Participants answered a set of questions about the event under instructions to keep their eyes open or closed. Instructed EC led to more correct answers ($d = 0.57$), with no difference in the rate of wrong answers. Perfect et al. (2008) investigated the effect of EC compared to a no-instruction control group in a series of five experiments which varied the nature of the event witnessed (a video-clip or live event) and the recall task (cued recall or free-narrative account). In all studies there was a benefit of instructed EC on recall of correct details with an (un-weighted) average effect size of $d = 0.98$. Instructed EC also led to a decrease in the number of incorrect details recalled, with an (un-weighted) average effect size of $d = -0.34$. In all studies, participants were free to withhold responses (i.e., say "don't know" to a question, or withhold a detail in free report), but EC had no impact upon willingness to provide an answer. Instead, EC increased the *accuracy* of what was reported. Beneficial effects of EC have also been reported for videos of violent events (Vredeveldt et al., 2011), for increasing correct recall of coarse-grain visual and auditory details of a violent video-clip and for decreasing incorrect recall of visual details (Vredeveldt et al., 2012), with a delay of 1 week prior to test (Vredeveldt et al., 2013), when there is a shift in context between event and test environment (Vredeveldt and Penrod, 2013) and with child witnesses (Mastroberardino et al., 2012).

Another line of research has manipulated levels of environmental distraction during retrieval. Perfect et al. (2012) manipulated the amount of visual distraction during retrieval of details about a videotaped event. Distraction took the form of colored squares changing location (to one of the four corners of the screen) every 1.5 s. In the simple distraction conditon a single box moved, whilst in the complex condition two (differently colored) boxes moved simultaneously. Increased distraction did not alter willingness to answer but it led to fewer correct and more incorrect answers, with large effect sizes of $d = 2.05$ and $d = -1.78$, respectively. Vredeveldt et al. (2011) manipulated visual and auditory distraction during retrieval under four conditions: participants were presented with a stream of Hebrew words which either appeared in random locations on a screen or were spoken out aloud (both high distraction) or were asked to close their eyes or look at a black screen (both low distraction). Once again, there was no difference in participants' willingness to answer a question but high distraction led to fewer correct and more incorrect answers (effect sizes, $d = 0.48$, $d = -0.40$, respectively). Two studies looking at the effect of distraction on visual memory (Wais et al., 2010; Wais and Gazzaley, 2011) also found that distraction decreases retrieval-accuracy. In both, participants studied images of objects appearing either singularly or in multiples (up to four of the same object on the same image slide) and were later given a verbally presented memory test in which participants had to say how many exemplars they had seen previously (0 for new items, or 1–4 for items shown previously). Both studies reported that visual and auditory distraction (participants looked at a picture of an outdoor scene or listened to pre-recorded noise from a restaurant) reduced the accuracy of the judgment of how many exemplars had previously been presented (average effect size of $d = 0.50$). Perfect et al. (2011) examined both environmental distraction and the potential benefit of EC. Participants answered questions about a staged event in conditions of quiet, or with white noise as distraction, either with instructed EC, or a no-instruction control. The effects of the white noise were to increase the rate of wrong answers provided, but this effect was reduced in participants instructed to close their eyes.

Thus there is a fairly clear pattern of effects for environmental distraction (or its removal though EC): increasing the level of distraction in the environment decreases retrieval-accuracy, often without changing response bias, whilst suppressing the influence of the environment through instructed EC increases retrieval-accuracy, even compared to a no-instruction control that may involve some EC or gaze aversion.

Surprisingly, given the ubiquity of studies of verbal memory, only one study has reported the simple effects of environmental distraction at retrieval on recall of words studied in lists. Glenberg et al. (1998) widely cited and influential paper reported a series of studies looking at gaze aversion and EC and also, looked at simple distraction effects on word-list recall.

In Experiment 5 of Glenberg et al. (1998) participants were presented with a total of ten 15-word word-lists, each followed by a 20 s arithmetic filler task, followed by a 30 s verbal recall period for the list items. During this participants either looked at a screen showing a picture of a sunset (static distraction) or watched a silent movie-clip from a Charlie Chaplin film (dynamic distraction). However, somewhat unexpectedly, the authors do not report recall performance for all target items in a list, and nor do they report the effect of list order: instead they report the effects of distraction only for the middle five words from each list, averaged over the 10 word-lists. This analysis revealed that distraction slightly reduced correct recall of mid-list items ($d = 0.29$: a small to medium effect size, Cohen, 1992).

Thus, despite being widely cited, the one study to look at environmental distraction effects on list recall found only a small effect, under highly atypical conditions: when multiple similar lists were studied, with only the mid-list items compared, and with a manipulation of distraction that compared a static photograph with a silent movie. What is unclear is the role of these factors in producing the effect, and thus the replicability and generalizability of the effect. Consequently, we set out to replicate Glenberg et al. (1998) Experiment 5 with a more closely controlled manipulation of distraction, and with analyses that looked at recall for all items on the list. The broader issue of our research is to further understand memory by investigating the mechanism by which environmental distraction disrupts memory recall. We used dynamic visual noise (DVN) as our distraction stimuli, and contrasted the effects of DVN with a static version of a DVN stimulus, which we hereafter refer to as static visual noise (SVN). **Figure 1** provides an example SVN image, along with the details of the nature of DVN. The negative effects of DVN have been reported in several memory studies: when words are recalled using a pegword mnemonic, (McConnell and Quinn, 2000; Andrade et al., 2002; Quinn and McConnell, 2006), when identifying visual changes in patterns (Dean et al., 2008), and when high imagery words rather than low imagery words are recalled (Parker and Dagnall, 2009). The aim of Experiment 1 was simply to replicate Glenberg et al. (1998) Experiment 5 as closely as possible, with a semantically neutral form of distraction, and then to analyse the data more thoroughly in order to determine the generality of any distraction

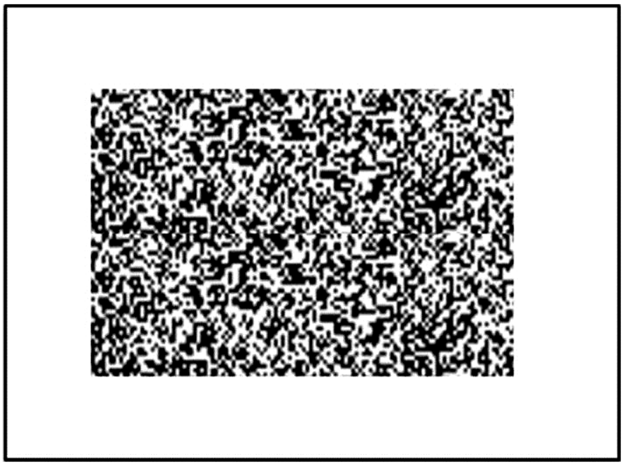

FIGURE 1 | Static visual noise (SVN), a screen of random black and white squares. Dynamic visual noise (DVN) is achieved by changing black boxes (10 × 10 pixels) to white and vice versa at a rate of 291 per second.

effect. As effects of EC on word-list recall have not yet been explored, we also included a third condition where participants were instructed to close their eyes during word-list recall. However, as we explain below, we were not able to analyse these data.

EXPERIMENT 1

The following three Experiments were carried out in line with ethical standards as set out by the University of Plymouth, School of Psychology ethics committee. Throughout the following analyses an alpha level of 0.05 was used, however, we further explored any numerical trends where $0.05 < p < 0.075$.

METHOD

Participants

Thirty-nine participants (24 females), average age 25.9 years ($SD = 9.33$) took part for course credit or as a paid volunteer. All participants had normal or corrected to normal vision and were fluent English speakers. All participants were made aware that the study involved being exposed to onscreen flickering; anyone concerned about this effect or with a history of seizures or migraines was excluded from the study. One participant's data (male, aged 28 years) was excluded from analysis due to failure to comply with procedural instructions (consistently looking away from the visual distractor) and another (female, aged 20 years) was incomplete due to being interrupted by a fire-alarm.

Materials

Word-lists. One-hundred and fifty words were randomly selected from the 1,080-word Toronto Word Pool (Friendly et al., 1982). This selection was used to randomly generate (without replacement) a unique set of 15 lists of 15-words for each participant.

Filler task. A pool of 150 two-addend addition sums (e.g., 24 + 3 =) was created from which 15 sets of 10 sums were randomly selected without replacement, for each participant.

Distraction conditions. Static visual noise and DVN were presented on a computer screen using parameters set out by McConnell and Quinn (2000): each field measured 700 × 700 pixels and consisted of a random pattern of 10 × 10 pixel blocks of black and white squares. This field was static during the SVN condition but appeared to flicker during the DVN condition as random pixel blocks changed color from black to white to black at a rate of 291 per second (see **Figure 1**). The surrounding background screen was white. A third condition of EC was also included and during the recall period under this condition, the program displayed a blank white screen for the entire recall period. The order in which SVN, DVN and EC conditions were presented was randomized across the 15-word-lists.

Procedure

Participants studied lists of individual words presented visually for 2 s each, with an inter-stimulus interval of 150 ms. Words were centered in the middle of the screen and appeared in black capital Arial-font, size 18. A series of 10 sums immediately followed the presentation of each word-list; each sum was shown center screen for 2 s at a time with a 200 ms inter-stimulus interval between sums. Participants were asked to verbally provide the solution to each sum as it appeared on the screen but were informed that answers were not being recorded or scored. All participants answered all sums. Following the last sum an onscreen instruction asked participants to either "Keep looking at the screen" (for SVN and DVN conditions) or informed them that they should keep their "Eyes-closed"; this instruction remained for 2 s and was followed by a fixed 30 s recall period. During the fixed recall period, participants verbally recalled words from the word-list they had just seen whilst looking at a screen which displayed SVN or DVN for the entire 30 s, or keeping their eyes-closed. Prior to the start of the experiment participants were informed that the experimenter would check to see if they complied with the instructions to look at the screen or close their eyes; although it was rarely required, a verbal reminder was given when necessary. The experimenter was seated adjacent to participants such that participants were unable to make eye-contact with the experimenter during encoding or retrieval phases. Across all participants, four words were recalled outside the 30 s recall period and these were excluded from analysis. Each participant recalled from five word-lists under SVN, five under DVN, and five under EC instructions in a randomized order: participants were not aware which recall condition would be used until after the word-list had been presented. At the end of each fixed recall period, which was signaled by a tone, participants pressed the space bar when ready to continue to the study phase for the next word-list.

RESULTS AND DISCUSSION

Our first analysis was designed to replicate the mid-list analysis reported in Glenberg et al. (1998). Additionally, because we were interested in the generality (vs. specificity) of any distraction effect across items, we also looked at the effects of distraction on recall for items from the start and end of each list. Consequently, we ran the analysis of recall split by third of list (first-, mid-, and last-5 items for each list). We had also intended to explore whether instructed EC improved recall. However, upon inspection of the data from the EC condition it became clear that a coding error in the program had resulted in the EC condition being not properly counterbalanced across list order, and so we dropped this condition from the analysis. This error did not affect the comparison of the DVN and SVN conditions. Further details are available from the first author upon request.

Throughout all the following analyses, Greenhouse–Geisser adjustments are reported wherever Mauchley's test of sphericity was significant.

A 3(Word Position: recall from first 5, middle 5, last 5 items in each list) × 2(Distraction: DVN vs. SVN) repeated measures ANOVA on correct recall showed there were no difference between the number of words recalled from the mid-list position of word-lists than from the first- and last-list positions, $F(1,36) = 2.40$, $p = 0.098$, MSE = 5.99, partial $\eta^2 = 0.063$ and nor was there a difference between the overall number of words recalled under DVN compared to SVN, $F(1,36) = 1.59$, $p = 0.215$, MSE = 6.25, partial $\eta^2 = 0.042$. However, as illustrated in **Figure 2**, fewer mid-list words were recalled under DVN than SVN, $F(2,72) = 7.90$, $p = 0.001$, MSE = 7.171, partial $\eta^2 = 0.18$. Test of simple main effects revealed no main effect of Distraction for the first- and last-5 words of each list ($F < 1$ in both cases), but a significant effect for the mid-list items, $F(1,36) = 7.86$, $p = 0.008$, partial $\eta^2 = 0.18$, replicating the effect reported in Glenberg et al. (1998).

Having observed an effect of distraction for mid-list items, we conducted a follow up analysis exploring the effect of list-order on this effect. This looked at whether the effect of distraction increases across lists by comparing mid-list correct recall from the first-two and last-two lists presented under each distraction condition with a 2(Distraction: DVN vs. SVN) × 2(List Position: first two lists vs. last two lists) repeated measures ANOVA on mid-list recall. There was no main effect of list position, $F(1,36) = 0.096$, MSE = 0.634, $p = 0.76$, partial $\eta^2 = 0.003$ but a main effect of distraction, $F(1,36) = 6.11$, MSE = 0.585, $p = 0.018$, partial $\eta^2 = 0.15$ and a numerical trend towards an interaction of distraction with list position, $F(1,36) = 3.46$, MSE = 0.38, $p = 0.071$, partial $\eta^2 = 0.09$, as illustrated in **Figure 3**. Simple main effects analysis revealed that the distraction effect was not significant for the first two lists ($F < 1$) but was significant for the last two lists, $F(1,36) = 9.25$, $p = 0.004$.

The final analysis looked at intrusion rates across lists. Because Glenberg et al. (1998) analysis was restricted to mid-list items, they did not look at intrusion rates because those could not be attributed to mid-list positions. Thus, their previously reported effect could have been due, in part, to distraction decreasing willingness to report (i.e., a criterion shift) rather than poorer memory. However, this did not appear to be the case here because there was a marginal increase in the rates of intrusions under distraction (DVN, $M = 3.51$, $SD = 2.88$; SVN, $M = 2.70$, $SD = 2.16$), $t(36) = 1.96$, $p = 0.06$, suggesting that distraction acts to reduce memory, rather than decreasing willingness to report.

Thus, we were successful in replicating the observed effect of distraction of mid-list items previously reported by Glenberg et al. (1998), using semantically neutral distraction. Additionally, distraction tended to increase error rates, in line with a memory deficit, rather than to reduce willingness to report. At first glance, these data appear to support the theoretical position advocated by Glenberg et al. (1998) and widely cited since, that visual distraction impairs moderately difficult recall. However, the other analyses challenge this theoretical position. First, overall recall for the full lists was not impaired by distraction: only memory for mid-list items. Therefore, the effects of distraction appear to be selective, rather than impairing memory generally. Second, the

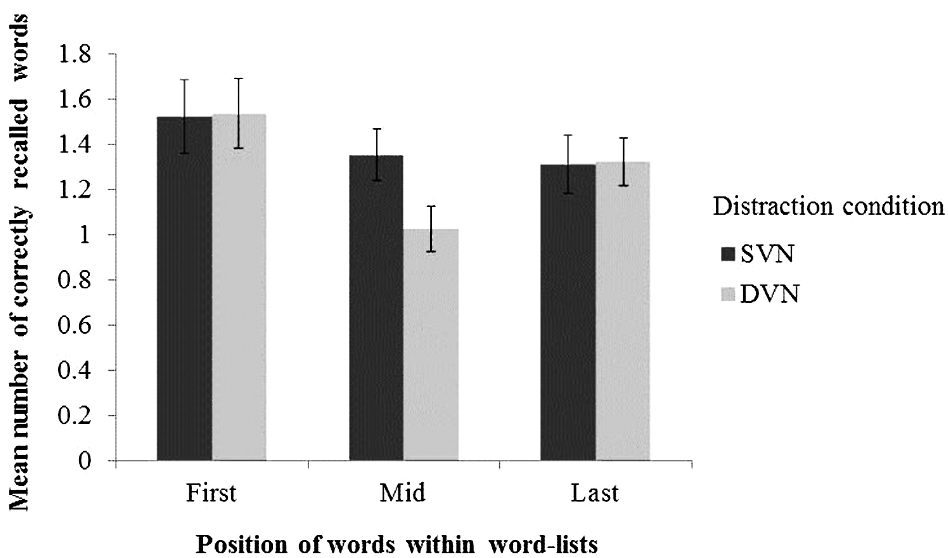

FIGURE 2 | The mean number of correctly recalled words from the First-, Mid-, and Last- five positions of each list. Error bars represent standard errors of the mean.

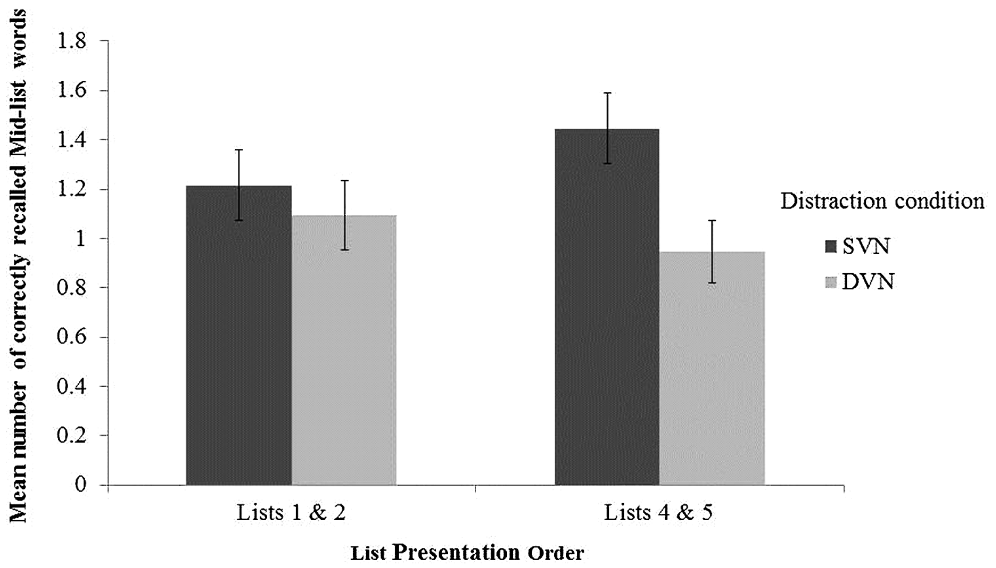

FIGURE 3 | The mean number of correctly recalled mid-list words from the first two- and last two- presented lists. Error bars represent standard errors of the mean.

analyses of the different thirds of the list suggest that difficulty, as indexed by performance in the SVN condition, does not predict the likelihood of detecting a distraction effect. In particular, the final list items were as hard to recall as the mid-list items, consistent with our use of a post-list filler task to remove recency effects (Postman and Phillips, 1965) but showed no distraction effect. Finally, the analysis of order suggests that the overall effect for the mid-list items increases as interference increases across lists, with no distraction effect apparent for the earlier lists studied. This pattern is also inconsistent with the claim that distraction affects difficult recall, because greater distraction effects were found at the end of the lists, when mid-list recall was higher under SVN.

Whilst Experiment 1 was able to replicate the pattern reported by Glenberg et al. (1998), the overall pattern of findings is not consistent with the idea that visual distraction produces general memory impairment, or even an impairment that particularly affects difficult-to-recall items. There is a suggestion that the effect might be related to the build-up of interference over multiple lists, first because both the original demonstration, and our own, occurred in conditions in which multiple similar lists were studied, but also because the effect appeared to increase across lists. However, this is not compelling, because of the within-subject manipulation of distraction type, which meant that the first list of a particular condition was not necessarily the first list studied. For instance, a participant may have recalled the first list under EC instructions, the second under DVN, and the third under SVN. Each of these would be the first list in each condition, but the amount of interference would not be equal. Consequently we decided to run two further studies in which we explore two potential reasons why mid-list items might be susceptible to distraction in a multiple list paradigm.

EXPERIMENT 2

Whilst the lack of a difference between the mid- and final-list items suggests that the difficulty of retrieval was not key to the distraction effect observed, this is not definitive because the argument rests upon a null effect. Consequently we decided to explore difficulty using a different manipulation. An alternate method for reducing the quality of memories to be retrieved is to impair their encoding. Consequently, in Experiment 2 we manipulated the presentation rate of the items. Participants either had 2 s per item (as in Experiment 1), or 0.5 s per item, with the clear expectation from the memory difficulty hypothesis that these items would be harder to recall, and so more susceptible to distraction.

The second potential explanation for the effects of distraction on mid-list items stems from the observation that the effect was stronger for later lists. The standard explanation for poorer recall with multiple lists is that there is a build-up of proactive interference (Keppell and Underwood, 1962), such that the later lists become increasingly difficult to distinguish from previous lists. Thus, a possible modification of the vulnerable memory hypothesis is that distraction impairs the ability to distinguish between competing memories: thus, distraction does not impair recall when there is little competition, but it does so as the trials progress. In order to explore this idea we wanted to have greater control of the order of presentation of lists in each condition. Consequently we moved to a between-subjects manipulation of distraction, so that we could look at performance on the first list under each distraction condition, free from any potential interference from a previous list recalled under a different condition. We did not include the EC manipulation in this study.

A secondary prediction that derives from an account based upon interference is that the distraction effects across lists should be removed if the interference is reduced by a change of list structure. Consequently, Experiment 2 used the release from proactive-interference paradigm (Wickens et al., 1963; Loess, 1968), in which the first four successive lists all contained items from the same semantic categories, but the fifth list consisted of items from different categories. Thus, the interference account would predict increasing effects of distraction across the first four lists, but less distraction effect for the fifth list. Of course if list order *per se* (rather than interference) was key to the effect previously seen in Experiment 1, perhaps as a result of fatigue or loss of motivation as the study progressed, then the distraction effect would be expected to grow for list five, not reduce.

METHOD

Participants

Sixty-four participants (38 females), average age 24.6 years ($SD = 10.02$) took part for course credit or as a paid volunteer.

Materials

In order to counterbalance the lists, we needed to move from 15- to 16-item word-lists. Ten 16-word high structured word-lists were created for this experiment from exemplars from 16 categories from Van Overschelde et al. (2004) semantic association norms. These were used to create two sets of five lists, both consisting of four interference lists (lists 1–4) and a release from interference list (list 5). Each interference list consisted of four exemplars from four different semantic categories (e.g., four professions, four fruits, four kinds of furniture, four animals). The fifth list consisted of four exemplars each from a different set of four categories. This process was repeated to create a second set of five lists, using different categories. For each participant, allocation of categories and items to list were randomly selected without replacement from the set of 16 categories. Mid-list items were defined as the middle six items, rather than five, with scores adjusted (by 5/6) when compared across list portions.

Procedure

The same basic procedure to Experiment 1 was followed, with participants studying and verbally recalling 10 successive lists, with the same filler task between study and test and participants unable to see the experimenter's face throughout encoding and recall. Unlike Experiment 1, participants always received the same distraction condition during the retrieval period, either SVN or DVN. Additionally there was a manipulation of presentation rate. Participants studied five consecutive word-lists with words presented for 0.5 s each (fast presentation) and five word-lists with words presented for 2 s (slow presentation), counterbalanced for order across participants.

RESULTS AND DISCUSSION

Experiment 2 was designed to explore two possible explanations for why DVN in Experiment 1 led to impaired mid-list recall of multiply presented lists: mid-list words are poorly encoded relative to the rest of the word-list; mid-list words are more susceptible to list inference than words in the rest of the list and either or both of these issues render mid-list recall vulnerable to distraction. In order to investigate these possibilities, we manipulated word presentation rate and list interference. We anticipated that presentation rates of 0.5 s vs. 2 s per word would lead to poorer encoding and therefore poorer recall and that repeatedly presenting same semantic category words across lists one to four (with a change in category for list five) would lead to a build-up of inter-list interference. In order to test the success of these manipulations, analysis first looked at the effect of presentation rate and list position (1–5) on overall correct recall.

Correct recall

The first analysis looked at correct recall, and the means are reported in **Table 1**. We ran a 2(Presentation rate: 0.5 s vs. 2 s) × 3(Word Position: first, mid, last items) × 5(List order: 1–5) × 2(Distraction: DVN vs. SVN) mixed ANOVA with repeated measures on all but the last factor. Overall, recall was better for slower presentation rates, $F(1,62) = 194.2$, $MSE = 1.22$, $p < 0.001$, partial $\eta^2 = 0.76$, was poorer for mid-list items than at other list positions, $F(2,124) = 8.41$, $MSE = 1.49$, $p < 0.001$, partial $\eta^2 = 0.12$, and showed a linear drop in correct recall across lists one to four, $F(1,62) = 112.45$, $MSE = 3.1$, $p < 0.001$, partial $\eta^2 = 0.65$ coupled with a significant increase in recall from list four to five, $F(1,62) = 27.64$, $MSE = 3.48$, $p < 0.001$, partial $\eta^2 = 0.31$.

Given that our manipulations produced the expected effects on recall, the effect of Distraction was unexpected. Overall, more correct items were recalled under DVN than SVN, $F(1,62) = 4.14$, $MSE = 11.15$, $p = 0.046$, partial $\eta^2 = 0.063$. Furthermore, Distraction did not reliably interact with any of the other factors in any combination (all ps > 0.16), and nor were there any other interactions (all ps > 0.093).

Incorrect recall

We ran a 2(Presentation rate: 0.5 s vs. 2 s) × 5(List order: 1–5) × 2(Distraction: DVN vs. SVN) mixed ANOVA on intrusion errors with repeated measure on all but the last factor, and the means are reported in **Table 2**. Overall the same number of incorrect words were given regardless of Presentation rate $F(1,62) = 2.79$, $MSE = 0.41$, $p = 0.10$, partial $\eta^2 = 0.043$, but there was a List order effect $F(2.81,174.53) = 12.036$, $p < 0.001$, $MSE = 0.675$, partial $\eta^2 = 0.163$ where repeated contrasts show that incorrect responses progressively increased from lists one to four but decreased for list five. More errors were produced under DVN than SVN, $F(1,62) = 6.43$, $MSE = 0.27$, $p = 0.014$, partial $\eta^2 = 0.094$, but there was no interactions between Distraction and Presentation rate, or List order ($F < 1$ in all cases).

First-list performance

Our original intention was to examine the nature of any overall distraction effect specifically for the first list. In line with the overall analyses, there were no effects of Distraction, nor any interactions involving Distraction, on correct recall or intrusions. To save space we do not report them here but full details are available from the first author on request.

Thus, in summary, although the manipulations of presentation rate and list interference manipulations were successful in moderating recall performance, they did not interact with the effects of distraction. Moreover, the main effects of distraction did not replicate that found in Experiment 1. Whilst distraction once again increased errors, it also increased correct recall. In fact, it appeared that the magnitude of the effects on correct and incorrect recall

Table 1 | The mean number of correctly recalled words under SVN and DVN for lists 1–5, with fast and slow presentation rates.

		SVN						DVN					
		First	***SE***	**Mid**	***SE***	**Last**	***SE***	**First**	***SE***	**Mid**	***SE***	**Last**	***SE***
Fast presentation	List 1	1.31	*0.20*	1.17	*0.17*	1.47	*0.18*	2.00	*0.20*	1.30	*0.17*	1.69	*0.18*
	List 2	1.19	*0.20*	0.78	*0.17*	1.22	*0.17*	1.44	*0.20*	1.25	*0.17*	1.22	*0.17*
	List 3	1.19	*0.20*	1.07	*0.15*	0.81	*0.15*	1.22	*0.20*	0.78	*0.15*	1.06	*0.15*
	List 4	0.97	*0.18*	1.02	*0.17*	0.94	*0.18*	1.09	*0.18*	0.73	*0.17*	1.00	*0.18*
	List 5	1.16	*0.19*	0.83	*0.16*	1.28	*0.18*	1.44	*0.19*	1.17	*0.16*	1.34	*0.18*
Slow presentation	List 1	2.56	*0.24*	2.06	*0.17*	2.38	*0.23*	2.50	*0.24*	2.37	*0.17*	2.31	*0.23*
	List 2	1.97	*0.20*	1.72	*0.19*	1.66	*0.22*	2.25	*0.20*	1.80	*0.19*	1.88	*0.22*
	List 3	1.88	*0.23*	1.38	*0.18*	1.59	*0.22*	1.59	*0.23*	1.46	*0.18*	1.75	*0.22*
	List 4	1.72	*0.23*	1.25	*0.18*	1.25	*0.17*	1.50	*0.23*	1.51	*0.18*	1.69	*0.17*
	List 5	2.00	*0.25*	1.74	*0.20*	1.84	*0.23*	2.16	*0.25*	2.16	*0.20*	2.31	*0.23*

Standard errors of the mean (SE) in italics.

Table 2 | The mean number of incorrectly recalled words under SVN and DVN for lists 1–5, with fast and slow presentation rates.

		SVN		DVN	
		Mean	***SE***	**Mean**	***SE***
Fast presentation	List 1	0.19	*0.09*	0.25	*0.09*
	List 2	0.47	*0.13*	0.59	*0.13*
	List 3	0.56	*0.17*	0.84	*0.17*
	List 4	0.47	*0.16*	0.91	*0.16*
	List 5	0.22	*0.09*	0.38	*0.09*
Slow presentation	List 1	0.13	*0.1*	0.31	*0.1*
	List 2	0.25	*0.13*	0.53	*0.13*
	List 3	0.5	*0.14*	0.69	*0.14*
	List 4	0.44	*0.19*	0.81	*0.19*
	List 5	0.06	*0.09*	0.31	*0.09*

Standard errors of the mean (SE) in italics.

was approximately the same, with an increase of Cohen's $d = 0.54$ in correct recall, and Cohen's $d = 0.63$ for errors. Thus, despite the increase in errors, there is little evidence to support the idea that DVN causes impairment of memory, but rather that it shifts willingness to report an answer that comes to mind. These patterns were not moderated by position of the words in the list. Thus these data do not appear to be consistent with inter-list interference and poor encoding as explanations for the distraction effect seen for mid-list items in Experiment 1 and seen in Glenberg et al. (1998) study.

One difference between the studies that showed an impairment of recall from distraction, and Experiment 2 is that the previous studies used entirely unstructured lists containing unrelated items both within- and across-lists. In contrast, Experiment 2 used list structure as a means of manipulating interference, and consequently used a restricted set of items. One possibility is that participants utilized this structure in their retrieval strategies and were able to overcome any environmental distraction. Consequently we looked at the role of list structure in Experiment 3, whilst controlling for item effects.

EXPERIMENT 3

In Experiment 2, interference came from both inter-list repeated categories and intra-list same-category words. That is, for a particular participant, each of the first 4 lists contained multiple exemplars from the same categories. So, although participants were clearly affected by the build-up of list interference (correct recall decreased across each set of lists 1–4 and incorrect recall increased), they may have adopted a recall strategy that used their knowledge of the list structure (i.e., the semantic categories contained in each list) which made them less susceptible to the negative effects of distraction. This experiment manipulated the degree of list structure (and cross-list similarity) whilst controlling for item effects by repeatedly sampling the same pool of 16 items from 16 categories. In the high structure condition, participants saw four exemplars from four categories successively for four lists, repeating this (with different categories) four times overall. In contrast, the low structure condition saw one exemplar from each of the 16 categories for 16 trials. Thus, across all lists, both conditions were matched for the items studied. However, the high structure condition resembled the structure used in Experiment 2, with the expectation that we would observe build-up of proactive-interference across the sets of four lists (with release from interference between sets). In contrast, the low structure condition resembled Experiment 1, in that the lists were as unstructured as they could be, given the constraint that the same set of items was used. If structure is the key difference between the first two studies, we expected to see a greater distraction effect for the unstructured condition than for the structured condition.

METHOD

Participants

Thirty-six participants (23 females), average age 22.6 years ($SD = 8.86$) took part for course credit or as a paid volunteer.

Materials

The same 16 category word-lists used in Experiment 2 were used to create a set of 16 high and 16 low structured word-lists, each consisting of 16-words. High structured lists were created in the same way as experimental lists one to four in Experiment 2, and thus constituted lists for which interference was expected to build-up over the four lists. Low structured lists were created by randomly selecting, without replacement, one word from each of the 16 category word-lists.

Procedure

Participants studied and then recalled either 16 high or 16 low structured-lists, under the same conditions as Experiment 1. The nature of the distraction was held constant for blocks of four lists, and then switched, with this repeated until all 16 lists had been tested, with participants recalling eight lists under DVN and eight under SVN, with order counterbalanced across participants. Otherwise, the experimental conditions replicated Experiment 2.

RESULTS AND DISCUSSION

Experiment 3 manipulated inter- and intra- list structure: we anticipated that high structured lists would build-up inter-and intra-list interference and impair recall (as was found in Experiment 2) to a progressively greater degree across lists one to four than low-structured lists. Therefore the analyses presented below for both full-list and mid-list correct and incorrect recall begins by seeking to confirm the success of this manipulation before looking at any effect of distraction on recall.

Correct recall

The first analysis looked at correct recall, and the means are reported in **Table 3**. We ran a 2(List structure: low vs. high) × 3(Word Position: first, mid, last items) × 5(List order 1–4) × 2(Distraction: DVN vs. SVN) ANOVA with repeated measure on all but the first factor. Overall, low-structured lists were recalled as well as high structured lists, $F(1,34) = 1.64$, $MSE = 8.39$, $p = 0.21$, partial $\eta^2 = 0.046$, but recall was poorer for mid-list items than for other list-position items, $F(2,57.16) = 10.55$, $MSE = 1.11$, $p < 0.001$, partial $\eta^2 = 0.23$. There was a linear drop in correct recall across lists one to four, $F(3,93.12) = 10.02$, $MSE = 0.53$, $p < 0.001$, partial $\eta^2 = 0.23$ with a one-way ANOVA on List order showing a linear decline for High structured lists, $F(1,68) = 15.58$, $p < 0.001$, $\eta^2 = 0.21$, but no such effect for Low structured lists, $F(1,68) = 0.51$, $p = 0.48$, $\eta^2 = 0.013$.

Although our manipulations produced the expected effects on recall, there was no overall main effect of Distraction, $F < 1$and no interactions involving Distraction at all (all ps > 0.10).

Incorrect recall

We ran a 2(List structure: low vs. high) × 4(List order 1–4) × 2(Distraction: DVN vs. SVN) mixed ANOVA on intrusion errors with repeated measure on all but the first factor, and the means are reported in **Table 4**. Overall, progressively more incorrect words were recalled across lists one to four, $F(2.3,78) = 5.22$, $MSE = 0.20$, $p = 0.005$, partial $\eta^2 = 0.13$, however, low- and high- structured lists did not differentially affect incorrect recall, $F < 1$. There was no main effect of Distraction, $F(1,34) = 1.61$, $MSE = 0.24$, $p = 0.21$, partial $\eta^2 = 0.05$ and there were no interactions involving Distraction (all ps > 0.28).

In short, this study found no reliable effects of distraction at all, despite once again demonstrating list position effects, and interference effects. Therefore the absence of a distraction effect in Experiment 2 does not appear to be a result of the high level of structure used in that Experiment. This does not rule out the possibility that the absence of evidence of an effect (and the presence of the effect in previous studies) reflects some unknown attributes of the items, because Experiment 3 used the same pool of items as Experiment 2, which was different from the set used for Experiment 1. However, whilst we cannot rule out this possibility, it does leave the theoretical explanation of the effect with little explanatory power, because any account would require that the negative effects

Table 3 | The mean number of correctly recalled First-, Mid-, and Last-list words under SVN and DVN for high- and low-structured lists 1–4.

		SVN						DVN					
		First	*SE*	Mid	*SE*	Last	*SE*	First	*SE*	Mid	*SE*	Last	*SE*
High structured	List 1	2.75	*0.27*	1.83	*0.21*	2.08	*0.22*	2.08	*0.30*	2.01	*0.21*	2.28	*0.23*
	List 2	2.11	0.27	2.00	0.22	1.75	0.24	2.39	0.27	2.09	0.23	1.89	0.21
	List 3	1.72	*0.21*	1.44	*0.19*	1.81	*0.23*	2.14	*0.32*	1.53	*0.22*	1.75	*0.26*
	List 4	1.75	*0.27*	1.67	*0.25*	1.81	*0.25*	1.56	*0.27*	1.30	*0.19*	1.83	*0.24*
Low structured	List 1	2.03	*0.27*	1.46	*0.21*	1.94	*0.22*	1.78	*0.30*	1.60	*0.21*	1.86	*0.23*
	List 2	1.92	*0.27*	1.30	*0.22*	1.61	*0.24*	1.78	*0.27*	1.48	*0.23*	1.56	*0.21*
	List 3	1.94	*0.21*	1.48	*0.19*	1.50	*0.23*	1.81	*0.32*	1.27	*0.22*	1.69	*0.26*
	List 4	1.44	*0.27*	1.20	*0.25*	1.75	*0.25*	2.00	*0.27*	1.20	*0.19*	1.89	*0.24*

Standard errors of the mean (SE) in italics.

Table 4 | The mean number of correctly recalled words under SVN and DVN for high- and low-structured lists 1–4.

		SVN		DVN	
		Mean	*SE*	Mean	*SE*
High structured	List 1	0.25	*0.14*	0.25	*0.12*
	List 2	0.47	*0.12*	0.61	*0.11*
	List 3	0.56	*0.13*	0.58	*0.12*
	List 4	0.86	*0.16*	0.56	*0.14*
Low structured	List 1	0.69	*0.14*	0.36	*0.12*
	List 2	0.42	*0.12*	0.33	*0.11*
	List 3	0.39	*0.13*	0.44	*0.12*
	List 4	0.61	*0.16*	0.53	*0.14*

Standard errors of the mean (SE) in italics.

of environmental distraction appears to occur only for particular items, studied as mid-list items of multiple lists.

GENERAL DISCUSSION

The main purpose of the studies was to investigate whether Glenberg et al.'s (1998) findings (Experiment 5) could be replicated, that is, whether visual distraction impairs verbal recall. Experiment 1 did find a moderately sized distraction effect for recall of the mid-list items, but this pattern was not replicated in either Experiment 2 or Experiment 3. Moreover, looking at data from the full word-lists presents a consistent negative picture. When analyzing memory for all the items in the list, there was no evidence of distraction impairing correct recall, whilst Experiment 2 showed that DVN *increased* full-list correct recall, albeit with a concomitant increase in errors. Results for incorrect recall were less consistent. Distraction had no effect on incorrect recall in Experiment 1 or Experiment 3 but, increased errors for multiple lists in Experiment 2.

The results of Experiments 2 and 3 clearly show effects of word presentation rate, interference and word position on recall; as the task became more demanding participants recalled fewer correct words and made more errors. Approximately one third of words were recalled from each word-list with no obvious floor or ceiling effects restricting our ability to detect an effect of distraction. Therefore, if visual noise competes with demanding retrieval processes for finite resources we would expect to have seen an effect on one of the tasks presented but we did not.

Figure 4 illustrates the overall pattern for the studies reported here, both for recall of mid-list items, and for recall of all items. This plots mean effect size and 95% confidence intervals around those effect sizes for each study. Glenberg et al.'s (1998) mean effect size is included for comparison, but no confidence intervals are available. This illustrates that five out of six potential effect sizes are compatible with their being no effect. The more optimistic reading of these data is that all studies are compatible with a very small effect: the confidence intervals calculated for each study all include the range $d = 0.12$ to $d = 0.15$. Thus, the appropriate conclusion to be drawn from the current series of studies is that there is either no impact of distraction upon recall from word-lists, or very little effect, irrespective of the difficulty of the memory materials.

This forces us to reconsider the central claim upon which the memory distraction effect was predicted: that the environment competes for cognitive resources with internal processing to the detriment of recall. In our studies, participants engaged in extensive and difficult memory retrieval tasks, for multiple lists of similar words presented at a fast rate. Performance was well below ceiling and so could be regarded as moderately demanding memory tests. At the same time our visual

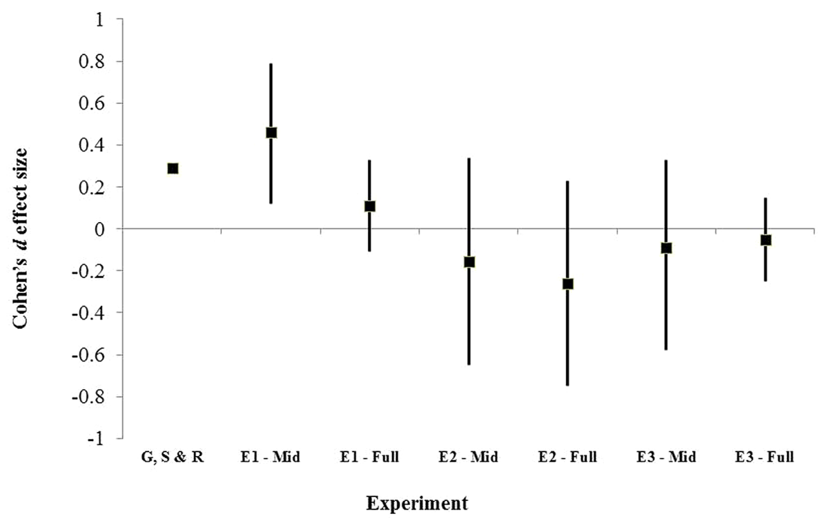

FIGURE 4 | The mean effect sizes (Cohen's d) and 95% confidence intervals for Mid-list and Full-list correct recall under DVN for Experiments 1 to 3 (E1–E3). Glenberg et al.'s (1998; G,S and R) mean effect size is included for comparison, but no confidence intervals are available.

distraction condition required participants to look directly at a screen containing flickering images, modeled on previous studies that have demonstrated that such images are distracting to cognitive performance (McConnell and Quinn, 2000; Andrade et al., 2002; Quinn and McConnell, 2006; Dean et al., 2008; Parker and Dagnall, 2009). And yet we observed little, if any effect on recall.

We cannot rule out the possibility that other forms of distraction or other forms of memory test might have produced a distraction effect. For example, it is feasible that word-list recall involves a comparatively large semantic component and a relatively small visual component. Thus a visual distractor which engages the semantic system (such as a film-clip) may affect recall more than a visual distractor that does not engage the semantic system (such as black and white squares). However, this explanation is not supported by Perfect et al. (2012) who found a strong effect of a semantically neutral visual distractor (colored boxes) on recall of auditory as well as visual details. Anecdotally we can report that we have run many attempts in our laboratory to find evidence for distraction effects on memory for word-lists, but without success. But the fact that a distraction effect is *possible* misses the point that the effect is not *inevitable*, and thus challenges the central tenet of the theoretical claim that environmental distraction competes for resources with internal processing resources during recall. The question is not whether environmental distraction does or does not produce an impairment of recall – because both have been shown – but under what conditions environmental distraction impairs recall. What needs explanation is why studies of event memory report moderate to large effect sizes for the negative effects of distraction and the positive effects of EC to reduce distraction, but the studies using memory for lists appear to show little, if any effect. Currently, we cannot offer a definitive reason for this distinction, but in the final section we offer a speculative account, based on an interesting study from the eyewitness field.

One possible explanation for the differential effect of distraction on event memory and memory for word-lists could be the role of contextual reinstatement (for a review see Smith, 2013). If mental reinstatement is used as a search strategy to retrieve details of episodic events, the richness of context information available for word-lists may be far diminished compared to that for events. Mentally reinstating a word-list, such as the ones presented in the experiments here, involves reinstating a white computer screen with black print at its center; there is very little context here to associate the word to, each word is presented on the same white screen so there are scarcely any other central contextual cues with which to discriminate each word from another. In this case, mental reinstatement will provide little benefit and semantic associations made at encoding may overshadow encoding of the impoverished central contextual environment. Likewise, the focus on semantic associations at retrieval may outshine or overpower the impoverished contextual cues. The result is that the physical central context may play a relatively small role in encoding and retrieving word-list items. On the other hand, mentally reinstating an event is rich with contextual cues within the source memory itself and as a result, the contextual cues from the event itself may be crucial in the recall of details from the event. Thus, an intriguing possibility is that distraction interferes with mental context reinstatement specifically. That is, the current environment can interfere with the ability to reconstruct a past context, rather than the ability to directly access memories. Thus, memories that benefit from the recreation of a past context (i.e., complex event details) are hindered by distraction whilst memories that can be accessed without context cues (i.e., semantic tokens presented in a sparse context) are not.

Consistent with this view, Vredeveldt and Penrod (2013) recently looked at the interaction between distraction reduction through EC, and context reinstatement. All participants witnessed an event in a busy street. Half were then interviewed in that street with lots of on-going distraction, and half in a quiet office, with little distraction. In each case, half had their eyes-closed. The hypothesis that environmental distraction competes with recall would predict that EC would be most beneficial in the busy street, but it was not. It was of most use in the quiet office, when witnesses had changed their retrieval context. Thus, even a quiet environment can be distracting if it conflicts with the ability to reconstruct the appropriate retrieval context, and a distracting New York city street can be non-distracting if it supports memory by providing useful cues.

REFERENCES

Andrade, J., Kemps, E., Werniers, Y., May, J., and Szmalec, A. (2002). Insensitivity of visual short-term memory to irrelevant visual information. *Q. J. Exp. Psychol.* 55, 753–774. doi: 10.1080/02724980143000541

Banbury, S. P., and Berry, D. C. (2005). Office noise and employee concentration: identifying causes of disruption and potential improvements. *Ergonomics* 48, 25–37. doi: 10.1080/00140130412331311390

Cohen, J. (1992). A power primer. *Psychol. Bull.* 112, 155–159. doi: 10.1037/0033-2909.112.1.155

Dean, G. M., Dewhurst, S. A., and Whittaker, A. (2008). Dynamic visual noise interferes with storage in visual working memory. *Exp. Psychol.* 55, 283–289. doi: 10.1027/1618-3169.55.4.283

Doherty-Sneddon, G., and Phelps, F. G. (2005). Gaze aversion: a response to cognitive or social difficulty? *Mem. Cognit.* 33, 727–733. doi: 10.3758/BF03195338

Friendly, M., Franklin, P. E., Hoffman, D., Rubin, D. C., and Carolina, N. (1982). The Toronto word pool: norms for imagery, concreteness, orthographic variables, and grammatical usage for 1,080 words. *Behav. Res. Methods Instrum.* 14, 375–399. doi: 10.3758/BF03203275

Glenberg, A. M., Schroeder, J. L., and Robertson, D. A. (1998). Averting the gaze disengages the environment and facilitates remembering. *Mem. Cognit.* 26, 651–658. doi: 10.3758/BF03211385

Kendon, A. (1967). Some functions of gaze-direction in social interaction. *Acta Psychol.* 26, 22–63. doi: 10.1016/0001-6918(67)90005-4

Keppell, G., and Underwood, B. J. (1962). Proactive inhibition in short-term retention of single items. *J. Verbal Learning Verbal Behav.* 1, 153–161. doi: 10.1016/S0022-5371(62)80023-1

Loess, H. (1968). Short-term memory and item similarity. *J. Verbal Learning Verbal Behav.* 7, 87–92. doi: 10.1016/S0022-5371(68)80169-0

Markson, L., and Paterson, K. B. (2009). Effects of gaze-aversion on visual-spatial imagination. *Br. J. Psychol.* 100, 553–563. doi: 10.1348/000712608X371762

Mastroberardino, S., Natali, V., and Candel, I. (2012). The effect of eye closure on children's eyewitness testimonies. *Psychol. Crime Law* 18, 245–257. doi: 10.1080/10683161003801100

McConnell, J., and Quinn, J. G. (2000). Interference in visual working memory. *Q. J. Exp. Psychol.* 53, 53–67. doi: 10.1080/713755873

Parker, A., and Dagnall, N. (2009). Concreteness effects revisited: the influence of dynamic visual noise on memory for concrete and abstract words. *Memory* 17, 397–410. doi: 10.1080/09658210902802967

Perfect, T. J., Andrade, J., and Eagan, I. (2011). Eye closure reduces the cross-modal memory impairment caused by auditory distraction. *J. Environ. Psychol. Learn. Mem. Cogn.* 37, 1008–1013. doi: 10.1037/a0022930

Perfect, T. J., Andrade, J., and Syrett, L. (2012). Environmental visual distraction during retrieval affects the quality, not the quantity, of eyewitness recall. *Appl. Cogn. Psychol.* 26, 296–300. doi: 10.1002/acp.1823

Perfect, T. J., Wagstaff, G. F., Moore, D., Andrews, B., Cleveland, V., Newcombe, S., et al. (2008). How can we help witnesses to remember more? It's an (eyes) open and shut case. *Law Hum. Behav.* 32, 314–324. doi: 10.1007/s10979-007-9109-5

Postman, L., and Phillips, L. (1965). Short-term temporal changes in free recall. *J. Exp. Psychol.* 17, 132–138. doi: 10.1080/17470216508416422

Quinn, J. G., and McConnell, J. (2006). The interval for interference in conscious visual imagery. *Memory* 14, 241–252. doi: 10.1080/09658210500210019

Smith, S. M. (2013). "Effects of environmental context on human memory," in *SAGE Handbook of Applied Memory,* eds T. J. Perfect and D. S. Lindsay (London: SAGE Publciations Ltd), 162–182.

Van Overschelde, J. P., Rawson, K. A., and Dunlosky, J. (2004). Category norms: an updated and expanded version of the Battig and Montague (1969) norms. *J. Mem. Lang.* 50, 289–335. doi: 10.1016/j.jml.2003.10.003

Vredeveldt, A., Baddeley, A. D., and Hitch, G. J. (2012). The effects of eye-closure and "ear-closure" on recall of visual and auditory aspects of a criminal event. *Eur. J. Psychol.* 8, 284–299. doi: 10.5964/ejop.v8i2.472

Vredeveldt, A., Baddeley, A. D., and Hitch, G. J. (2013). The effectiveness of eye-closure in repeated interviews. *Legal Criminol. Psychol.* doi: 10.1111/lcrp.12013

Vredeveldt, A., Hitch, G. J., and Baddeley, A. D. (2011). Eyeclosure helps memory by reducing cognitive load and enhancing visualisation. *Mem. Cognit.* 39, 1253–1263. doi: 10.3758/s13421-011-0098-8

Vredeveldt, A., and Penrod, S. D. (2013). Eye-closure improves memory for a witnessed event under naturalistic conditions. *Psychol. Crime Law* 19, 893–905. doi: 10.1080/1068316X.2012.700313

Wagstaff, G. F., Brunas-Wagstaff, J., Cole, J., Knapton, L., Winterbottom, J., Crean, V., et al. (2004). Facilitating memory with hypnosis, focused meditation, and eye closure. *Int. J. Clin. Exp. Hypn.* 52, 434–455. doi: 10.1080/00207140490889062

Wais, P. E., and Gazzaley, A. (2011). The impact of auditory distraction on retrieval of visual memories. *Psychon. Bull. Rev.* 18, 1090–1097. doi: 10.3758/s13423-011-0169-7

Wais, P. E., Rubens, M. T., Boccanfuso, J., and Gazzaley, A. (2010). Neural mechanisms underlying the impact of visual distraction on retrieval of long-term memory. *J. Neurosci.* 30, 8541–8550. doi: 10.1523/JNEUROSCI.1478-10.2010

Wickens, D. B., Born, D. G., and Allen, C. K. (1963). Proactive inhibition and item similarity in short-term memory. *J. Verbal Learning Verbal Behav.* 2, 440–445. doi: 10.1016/S0022-5371(63)80045-6

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Effects of social gaze on visual-spatial imagination

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Previous research suggests that closing one's eyes or averting one's gaze from another person can benefit visual-spatial imagination by interrupting cognitive demands associated with face-to-face interaction (Markson and Paterson, 2009). The present study further investigated this influence of social gaze on adults' visual-spatial imagination, using the matrix task (Kerr, 1987, 1993). Participants mentally kept track of a pathway through an imaginary 2-dimensional (2D) or 3-dimensional (3D) matrix. Concurrent with this task, participants either kept their eyes closed or maintained eye contact with another person, mutual gaze with a person whose eyes were obscured (by wearing dark glasses), or unreciprocated gaze toward the face of a person whose own gaze was averted or whose face was occluded (by placing a paper bag over her head). Performance on the 2D task was poorest in the eye contact condition, and did not differ between the other gaze conditions, which produced ceiling performance. However, the more difficult 3D task revealed clear effects of social gaze. Performance on the 3D task was poorest for eye contact, better for mutual gaze, and equally better still for the unreciprocated gaze and eye-closure conditions. The findings reveal the especially disruptive influence of eye contact on concurrent visual-spatial imagination and a benefit for cognitively demanding tasks of disengaging eye contact during face-to-face interaction.

Keywords: visual-spatial imagery, eye-closure, gaze aversion, social interaction

INTRODUCTION

In situations involving interlocutory interactions, people often spontaneously close their eyes or look away from the interlocutor, particularly when asked difficult or probing questions (e.g., Glenberg et al., 1998; Doherty-Sneddon et al., 2002; Doherty-Sneddon and Phelps, 2005). Indeed, evidence that children are better at answering questions when their gaze is averted has led researchers to propose that children should use gaze aversion techniques in classroom settings to enhance learning (see, e.g., Doherty-Sneddon et al., 2001, 2002; Doherty-Sneddon and Phelps, 2005; Phelps et al., 2005).

Evidence for spontaneous eye-closure or gaze-avoidance when cognitive demands are particularly high is widely documented in observational studies of interlocutory interactions (typically between adults). For example, Kendon (1967) found that in filmed conversations participants averted their gaze for longer periods when speaking than when listening. Similarly, Ehrlichman (1981) observed that individuals who interacted with an interviewer on a video screen looked away from the screen more often when engaging in thinking or speaking than when listening to the interviewer. Both observations are consistent with individuals spontaneously averting their gaze to reduce environmental distraction when cognition is more demanding (e.g., thinking or producing speech compared to comprehension). Also consistent with this view, Beattie (1981) found in another observational study that looking continuously at an interviewer's face interfered with the production of spontaneous speech and suggested that emotional arousal brought about by eye contact with an interlocutor can disrupt the formulation of responses to questions.

Other research has used experimental methods to more fully reveal the benefits of eye-closure and gaze aversion for cognition. For instance, Glenberg et al. (1998) found that performance answering general knowledge and mathematics questions was particularly impaired when participants gazed at an experimenter's face and impaired to a lesser extent when they gazed at various visual stimuli, compared to when they closed their eyes. Glenberg et al. took these findings to indicate that gaze aversion is at least partly an effort to control cognitive load, whereby an individual averts their gaze in order to avoid input from environmental stimuli that may be irrelevant but disruptive to the task they are attempting to perform. Studies by Doherty-Sneddon et al. (2000, 2001, 2002), Doherty-Sneddon and Phelps (2005), Phelps et al. (2005) showed similar effects of gaze aversion on children's performance on question-answering tasks. Moreover, other research that has focused on the benefits of eye-closure for episodic memory shows that recall is better when an eyewitness closes their eyes (Perfect et al., 2008, 2011; Vredeveldt et al., 2011, 2012, 2013; Vredeveldt and Penrod, 2013). Similar benefits of eye-closure for episodic memory have also been observed in an experiment in which participants had to recall images presented as part of an earlier task, either with their eyes closed or while viewing a distracting visual stimulus (Wais et al., 2010).

These benefits of eye-closure and gaze aversion are often considered from the perspective of models of dual-task performance. According to this approach, memory retrieval and environmental monitoring are competing tasks that might either be conducted simultaneously (i.e., as dual tasks) or, when one task is particularly demanding, conducted sequentially as tasks that can be switched between. Accordingly, when cognitive task demands are high, it may be beneficial to reduce environment demands by closing one's eyes or averting one's gaze from external stimuli (see, e.g., Glenberg, 1997). However, eye-closure and gaze aversion may offer either a modality-specific benefit (and so benefit only aspects of visual processing) or more general, cross-modal benefits for cognition (for further discussion, see, e.g., Perfect et al., 2008). For example, the view that eye-closure provides a general enhancement to memory functioning is consistent with findings showing that closing one's eyes can improve memory for auditory as well as visual information (Perfect et al., 2008, 2011).

However, much research on the benefits of eye-closure and gaze aversion has been inspired by the multi-component model of working memory (e.g., Baddeley and Hitch, 1974; Baddeley, 1986), and often presumed that benefits will be modality-specific. A basic assumption of this model is that working memory is fractionated into two modality-specific subsystems (the visuospatial sketchpad and the phonological loop) and a multimodal subsystem (the episodic buffer), each of which are supervised by a central executive system. Dual task research has shown that the visual and phonological subsystems are subject to modality-specific interference. This, for example, entails that a concurrent secondary visual-spatial task, such as tapping out a specified pattern, will interfere with visual but not auditory memory processes (e.g., Brooks, 1968). Consequently, based on this approach, it is often argued that the disruptive influence of visual input, including that provided by eye contact with another person, is due to interference with modality-specific processing of visual information by the visual-spatial sketchpad (e.g., Wagstaff et al., 2004; Vredeveldt et al., 2011). Accordingly, eye closure or gaze aversion will specifically benefit the processing of visual-spatial information by eliminating or reducing visual interference from the environment. Additional support comes from research showing that eye-closure can enhance visual imagery (Caruso and Gino, 2011); which in turn has been shown to improve memory recall (e.g., Paivio, 1969, 1971; Jonides et al., 1975).

Doherty-Sneddon et al. (2001) conducted several experiments that more directly assessed the influence of distracting visual stimuli on the processing of visual-spatial information. These studies primarily were conducted with child participants and used various visual-spatial tasks, including the Corsi Block task (Corsi, 1972). In this task, an experimenter taps out a sequence on a set of identical spatially separated blocks and, after a short retention interval, the participant is required to reproduce this sequence. This enables the experimenter to assess the accuracy of recall for increasingly long spatial sequences. The findings were clearest for tasks, like the Corsi Block task, that included a memory component. These showed that performance was particularly poor if, during the retention interval, participants looked at someone's face or watched a complex visual stimulus, but better if they averted their gaze (by looking at the floor) or closed their eyes. However, because these tasks included a memory component, it is unclear whether the disruptive influence of distracting visual stimuli is restricted to memory for visual-spatial information or can also affect concurrent processing of this information.

Consequently, Markson and Paterson (2009) used the matrix task (Kerr, 1987, 1993) to specifically assess the effects of distracting visual stimuli on the concurrent processing of visual-spatial information. The matrix task is a path visualization task, typically used to assess the capacity for visualizing spatial information (Kerr, 1987, 1993; Fiore et al., 2011; see also Attneave and Curlee, 1983; Diwadkar et al., 2000; Lyon et al., 2008). Participants in this task are required to mentally keep track of pathways through imaginary matrices, which can vary in complexity. These matrices typically are formed from either a 2D array of squares or a 3D cube. In a typical trial, the participant is instructed to imagine a particular matrix and is informed of the starting point of a pathway through this matrix. The direction of each successive step in the pathway is then verbally described and, at the end of the trial, the participant is required to identify its end-point, and the accuracy of their response is recorded. A major advantage of this task is that it provides an assessment of the accuracy of the visualization of this pathway without testing recall, as the participant is only required to remember the end-point and not the full pathway.

Following Kerr (1987, 1993), Markson and Paterson (2009) manipulated task difficulty by employing 2D (i.e., 3 × 3) and 3D (i.e., 3 × 3 × 3) matrices. In two experiments, performance on these matrices was compared across trials in which participants engaged concurrently in different gaze behaviors. Participants either maintained eye contact with an experimenter, kept their eyes closed, or gazed continuously at a blank computer screen or one displaying a static visual image (i.e., a picture of a sunset or an upright or inverted photograph of the experimenter) or a dynamic visual stimulus (i.e., a silent video clip). The results showed that performance on both 2D and 3D tasks was poorer when participants maintained eye contact with the experimenter than in either the eye-closure condition or the other stimulus viewing conditions, which did not differ. Markson and Paterson took this to show that maintaining eye contact with another person can impair concurrent visualization of spatial information, whereas closing one's eyes or averting one's gaze from that person, by viewing a blank computer screen or a static or dynamic visual stimulus, does not. In line with Kerr's earlier findings (see also Fiore et al., 2011), performance was poorer for 3D than 2D matrices, but matrix complexity did not modulate the effects of eye-closure or averted gaze on task performance.

These experiments provide clear evidence that eye-contact with another person can disrupt visual-spatial imagination. However, it is unclear whether this disruption occurs only with eye contact or is also observed for other forms of social gaze. Various forms of social gaze can occur in social situations (e.g., Kleinke, 1986). This includes eye contact with another person, but also includes mutual gaze, in which two individuals gaze at each other's faces without making eye contact. It is also possible to gaze upon another person while not making eye contact or engaging in mutual gaze. The question addressed in the present research is whether these different forms of social gaze produce similar disruption to visual-spatial imagination. There is considerable evidence that faces provide important social information, but it is also widely argued that the eyes more than other facial features primarily convey this information (for a review, see Itier and Batty, 2009). Consequently, eye contact may be more cognitively demanding than other forms of social gaze, including mutual gaze and unreciprocated gaze on an individual.

Accordingly, to investigate this issue further, the present research used the matrix task to assess the influence of various forms of social gaze on the visualization of spatial information. As in the original Markson and Paterson (2009) study, we examined the influence of eye-closure and eye contact with another person on task performance. But, in addition, we introduced several novel social gaze conditions. For instance, we introduced a condition in which participants engaged in mutual gaze with an experimenter without making eye contact, by having the experimenter occlude their eyes by wearing dark glasses. In another condition, participants looked continuously toward an experimenter's face but were unable to make eye contact or engage in mutual gaze because the experimenter had averted her own gaze. Finally, we included a condition in which participants looked continuously toward the experimenter's face but were unable to make eye contact or engage in mutual gaze, or even view that person's face, because the experimenter had placed a paper bag over her head.

The logic of these additional social gaze conditions was straightforward. If cognitive demands associated with eye contact with another person are especially disruptive to visual-spatial imagination, performance on the matrix task should be impaired most in the eye contact condition. If mutual gaze also disrupts visualization, but to a lesser degree, performance should be better, in comparison with the eye contact condition, when only mutual gaze is possible. Moreover, performance should be better still when gaze is not reciprocated and therefore neither eye contact nor mutual gaze is possible (and this may be further enhanced by the occlusion of the experimenter's face when she has a bag over her head). Eye-closure should also show better performance than either eye contact or mutual gaze, but it remains to be seen whether performance differs between eye-closure and unreciprocated gaze. Both 2D and 3D matrices were used in the present research, in order to determine if standard effects of matrix complexity are observed (i.e., performance should be better for 2D than 3D tasks), and to ascertain if the influence of social gaze on the visualization of spatial information varies with matrix complexity.

MATERIALS AND METHODS

PARTICIPANTS

Thirty undergraduate psychology students from the University of Leicester took part in the experiment in exchange for course credits.

DESIGN

The experiment manipulated two within-participants independent variables. The first was the number of dimensions for the matrix and had two levels: 2D (3 × 3) and 3D (3 × 3 × 3) matrices. The second independent variable was the gaze condition, which had five levels: participants either kept their eyes closed, maintained eye contact with an experimenter whose eyes were fully visible, maintained mutual gaze with an experimenter whose eyes were obscured by wearing dark glasses, or gazed continuously toward the face of an experimenter who either averted their own gaze or whose face was occluded by placing a paper bag over her head. The dependent variable was the number of correct responses in the matrix task (i.e., responses that accurately identified the correct end-point of a pathway).

MATERIALS AND APPARATUS

The 2D matrix was drawn in black ink on white cardboard. Each square of the matrix was 4 cm^2. The 3D matrix was built from wooden blocks, each measuring 4 cm^3. The pathways were based on those used by Markson and Paterson (2009). Each pathway had a designated starting square or block and comprised seven statements expressing a sequence of one unit moves in either up, down, left and right directions for the 2D matrix and also forward and backward directions for the 3D matrix. No directional term appeared more than twice consecutively in each sequence. Audio-recordings of these directional statements were played to participants and served to provide directional instructions in each gaze condition. The directional statements were recorded with an interval rate of 0.5 s, read to the time of a metronome, as this was the presentation rate at which Kerr (1993) observed clear differences in performance between 2D and 3D matrices.

PROCEDURE

Participants took part individually and were told they were taking part in a study of perceptual processing. Written instructions on how to complete the task were given to participants, and participants took part in two practice trials, one for a 2D matrix and one for a 3D matrix, before beginning the experiment. Participants were instructed to maintain eye contact with an experimenter in the eye contact condition, to maintain gaze toward the experimenter's eyes in the mutual gaze condition, and to maintain gaze in the direction of the experimenter's face in the unreciprocated gaze conditions. In the eye-closure condition, participants were instructed to keep their eyes firmly closed throughout the trial. A second experimenter checked compliance with these instructions and repeated the instructions between trials as a reminder if this proved necessary. Participants stood 1.5 m from the experimenter in each social gaze condition.

At the beginning of each trial, the experimenter showed either the 2D or 3D matrix to the participant and indicated the matrix's starting point. The matrix was then removed from the participant's view, and the directional instructions for that trial were played to the participant. Throughout each trial, the experimenter remained silent, stationary, and expressionless. At the end of the trial, the experimenter showed the matrix to the participant and asked them to indicate the final square or block in the pathway that had been described. The participant's response was then recorded. Each participant performed four 2D and four 3D trials in each social gaze condition, in five separate blocks that were counterbalanced for order across participants. The experiment lasted approximately 40 minutes per participant.

RESULTS

The mean performance accuracy for 2D and 3D matrices in each social gaze condition is shown in **Figure 1**.

Performance on the matrix task was analyzed using 2 (matrix complexity) × 5 (gaze condition) analysis of variance (ANOVA), and the Greenhouse–Geisser correction was used where appropriate. The analysis revealed a significant main effect of Matrix Complexity, $F(1,29) = 272.10$, $p < 0.001$, $\eta_p^2 = 0.90$. This was due to participants making more correct responses for 2D matrices ($M = 3.9$) than 3D matrices ($M = 2.1$). This replicated earlier findings (Kerr, 1987, 1993; Markson and Paterson, 2009; Fiore et al., 2011). There was also a significant main effect of Gaze Condition, $F(4,76) = 58.87$, $p < 0.001$, $\eta_p^2 = 0.67$, and a significant interaction that revealed that the influence of Gaze Condition was modulated by Matrix Complexity, $F(4,76) = 19.78$, $p < 0.001$, $\eta_p^2 = 0.41$. This interaction was explored further using a Bonferroni-corrected *t*-test. For the 2D task, performance was poorer for eye contact compared to the other gaze conditions (eye contact vs. mutual gaze, $p < 0.01$, $d = 0.56$; eye contact vs. averted gaze, $p < 0.01$, $d = 0.57$; eye contact vs. bag over head, $p < 0.01$, $d = 0.50$; eye contact vs. eye-closure, $p < 0.01$, $d = 0.56$). No other differences were significant ($p > 0.15$, $d < 0.30$).

For the more difficult 3D task, performance also was poorer for eye contact compared to the other gaze conditions (eye contact vs. mutual gaze, $p < 0.001$, $d = 1.08$; eye contact vs. averted gaze, $p < 0.001$, $d = 2.04$; eye contact vs. bag over the head, $p < 0.001$, $d = 1.57$; eye contact vs. eye-closure, $p < 0.001$, $d = 1.98$). In addition, performance was poorer for mutual gaze compared to either averted gaze ($p < 0.01$, $d = 0.73$), occluding the experimenter's face by placing a bag over her head ($p < 0.001$, $d = 0.63$), or eye-closure ($p < 0.001$, $d = 0.89$). No other differences were significant ($p > 0.05$, $d < 0.04$). The indication, therefore, is that maintaining eye contact with another person is especially disruptive to accurate mental visualization of a pathway through a matrix. Moreover, mutual gaze is also disruptive to accurate visualization of this pathway, but less so than eye contact. Finally, social gaze conditions in which gaze is not reciprocated and so eye contact and mutual gaze are not possible are no more disruptive to this visualization than eye-closure[1].

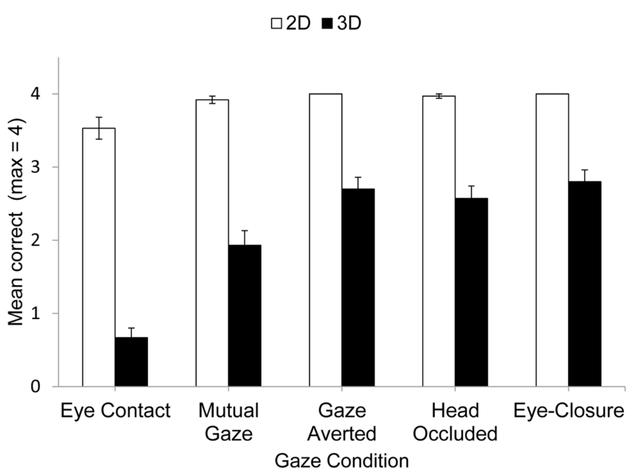

FIGURE 1 | Mean correct responses in 2D and 3D matrix tasks. Bars correspond to standard errors.

DISCUSSION

The results of this experiment were very clear. In line with previous studies, more correct responses were produced for 2D than 3D matrices (Kerr, 1987, 1993; Markson and Paterson, 2009; Fiore et al., 2011). Consequently, participants in the present experiment showed similar sensitivity to matrix complexity as participants in previous research. In addition, as in previous research which used the matrix task to investigate effects of eye-closure and gaze aversion on visual-spatial imagination (Markson and Paterson, 2009), maintaining eye contact with another person disrupted an individual's ability to keep track of a pathway through an imaginary matrix in both 2D and 3D versions of the task. Performance on 2D matrices in the other social gaze conditions did not differ and was at ceiling. However, performance in the 3D matrix task revealed important differences between social gaze conditions. For this more difficult matrix task, performance was poorest for the eye contact condition, better for mutual gaze, and better still in conditions in which gaze was not reciprocated and so neither eye contact nor mutual gaze was possible. Interestingly, the unreciprocated gaze conditions did not differ in performance, indicating that occluding the experimenter's face did not bring additional benefits to performance. Moreover, both unreciprocated gaze conditions produced as good performance as eye-closure. Consequently, the indication from the present findings is that maintaining eye contact with another individual is singularly disruptive to visual-spatial imagination. Mutual gaze is also disruptive to visual-spatial imagination but less so than eye contact. Finally, other forms of social gaze that do not require reciprocation (i.e., maintaining gaze on someone who has averted their own gaze or whose face is occluded) produced the same level of performance as eye-closure, and

[1]Non-parametric analyses of the effects of the different gaze conditions on task performance were conducted separately for 2D and 3D tasks using the Friedman Test (Siegel and Castellan, 1988). This confirmed there was a significant effect of gaze condition for the 2D task, $\chi^2(4) = 27.06$, $p < 0.001$, and for the 3D task, $\chi^2(4) = 66.12$, $p < 0.001$. *Post hoc* analyses were conducted using a Bonferroni-corrected Wilcoxon Test. For the 2D task, performance was poorer in the eye contact condition compared to the other gaze conditions (*p*s < 0.01). For the 3D task, performance was poorer in the eye contact condition compared to the mutual gaze condition ($p < 0.01$), and for the mutual gaze condition compared to the unreciprocated gaze and eye-closure conditions (*p*s < 0.01). Thus, the principle findings of this experiment were upheld using these non-parametric statistical analyses.

so appear not to disrupt the visualization of spatial information.

The present findings are in line with previous findings by Markson and Paterson (2009) who observed that performance on 2D and 3D matrices was especially disrupted by maintaining eye contact with another person, but that performance was largely unaffected by other forms of visual stimuli. In particular, it had previously been suggested that processing faces requires visual-spatial working memory resources and that averting gaze from a person's face, or closing one's eyes, can preserve these working memory resources for use in other cognitive tasks (Doherty-Sneddon et al., 2001). Consequently, viewing an image of a person's face might be expected to be disruptive to visual-spatial processing. However, Markson and Paterson found that gazing upon either an upright image of the experimenter's face or an inverted image of the experimenter's face (which might be expected to be less disruptive) produced similar performance to eye-closure. It therefore appeared that demands associated with processing the image of a face did not interfere with the concurrent visualization of spatial information. The present findings expand on these previous findings by showing that face processing may only be disruptive to a visualization task when a live person is involved and this is accompanied by eye contact or mutual gaze.

Such findings are not particularly surprising given the substantial evidence for the special status of eye contact and mutual gaze in social situations. Indeed, there is abundant evidence that looking at another person's face, and particularly their eyes, provides a wealth of complex cognitive information. This can include information about the other person's direction of gaze and their emotional and mental states, but eye contact also plays an important role in regulating social interaction by, for example, providing cues to turn-taking during conversation (for a review see, Frischen et al., 2007). Looking at the eyes of another person has also been shown to elicit a host of social cognitive and affective responses, including heightened self-awareness and a sense of intimacy (e.g., Argyle, 1981; Kleinke, 1986). Indeed, physiological evidence shows that eye contact in particular increases skin conductance and produces higher scores on subjective self-assessments of emotional arousal and valence compared to averted gaze or looking at a picture of a person (Hietanen et al., 2008; Akechi et al., 2013). Moreover, recent electrophysiological research has revealed differences in the neural response to viewing another person in the same room compared to viewing that person on a computer screen or in a photograph, and that viewing a live face with direct gaze is processed more intensely than a face with averted gaze or closed eyes (Pönkänen et al., 2011). Consequently, it seems likely that the especially disruptive effect of eye contact on visual-spatial imagination in the present experiment and in the earlier research by Markson and Paterson (2009) is related to the heightened cognitive and social demands associated with maintaining eye contact with a live person. These demands are lessened in mutual gaze conditions and appear to be effectively eliminated when both eye contact and mutual gaze are prevented.

By comparison with previous studies of memory for visual-spatial information (Doherty-Sneddon et al., 2001), there was no evidence for a more extensive influence of visual interference on task performance. Doherty-Sneddon et al. (2001) found that the performance of child participants who performed visual-spatial memory tasks was poorer in conditions in which they viewed a dynamic visual stimulus compared to when they closed their eyes or averted their gaze (by looking at the floor) in the interval between viewing the test stimuli and providing a response. However, there was no indication from the experiments by Markson and Paterson (2009) that viewing either static or dynamic images is any more disruptive to visual-spatial imagination than averting one's gaze or closing one's eyes. Similarly, the present experiments show no benefit for eye-closure over situations in which participants gaze at another person without making eye contact or engaging in mutual gaze. Thus, it appears that visual input is not a significant source of interference in the matrix task, but social interaction involving either eye contact or mutual gaze is.

The particular advantage of the matrix task is that it provides an assessment of visual-spatial processing separate from memory for this information. Consequently, findings obtained with the matrix task may differ from those obtained with other tasks because it provides an assessment of effects associated with visual-spatial imagery rather than the retention of this information or its retrieval from memory. A further important difference is that whereas the present research (and the original experiments by Markson and Paterson, 2009) investigated effects of eye-closure and gaze aversion on visualization of spatial information by adult participants, the earlier work by Doherty-Sneddon et al. (2001) focused on these processes in children. Consequently, further research is required to determine if the contrast in the findings obtained in these studies reflect this difference in the age of the participants.

An important additional advantage of the matrix task over other tests of visual-spatial processing is that it provides an effective means of assessing the influence of the social environment on visual-spatial imagery. Indeed, while the present experiment provides insight into the influence of social demands on task performance, various factors remain to be investigated. For instance, a factor which may be particularly important is the social distance between the participant and the experimenter when performing the matrix task. Indeed, pilot data from our laboratory suggest that effects of eye contact are mediated by the physical proximity of the participant and the experimenter, and that effects of eye contact may be obtained only at standard social distances (i.e., when the participant and the experimenter are approximately 1 m apart, e.g., Argyle and Dean, 1965). These pilot data suggest that the influence of eye contact may be disrupted at closer distances and dissipate when the participant and experimenter are further apart (i.e., 3 m or more apart), although further research is required to fully establish these effects.

Markson and Paterson (2009) also argued that a particularly important avenue of research might involve assessing effects of individual differences in social anxiety or shyness on task performance, as individuals scoring high on these characteristics may show heightened sensitivity to social demands when eye contact is made compared to when gaze is averted or the individual closes their eyes (see also Moukheiber et al., 2012). Indeed, if eye-closure or gaze aversion benefit cognition by individuals who suffer acutely from social anxiety or shyness, it may be advantageous to encourage these individuals to adopt these techniques in relevant settings (e.g., in the classroom). However, it is also important to note that negative social judgments frequently are made of individuals who avert their gaze or turn away from an interlocutor (e.g., Larsen and Shackelford, 1996), especially as people who avert their gaze are often perceived as deceptive by others (for discussion see, e.g., Vrij and Semin, 1996; Mann et al., 2002; Einav and Hood, 2008). Finally, as noted already, the present studies used only adult participants. Consequently, an obvious future direction for this research would be to examine how children perform in the matrix task. Such experiments could include manipulations of social gaze or social proximity and would have the potential to reveal development changes in the influence of the social situation on the performance of cognitively demanding tasks.

REFERENCES

Akechi, H., Senju, A., Uibo, H., Kikuchi, Y., Hasegawa, T., and Hietanen, J. K. (2013). Attention to eye contact in the West and East: autonomic responses and evaluative ratings. *PLoS ONE* 8:e59312. doi: 10.1371/journal.pone.0059312

Argyle, M. (1981). *Bodily Communication*. London, England: Methuen.

Argyle, M., and Dean, J. (1965). Eye-contact, distance, and affiliation. *Sociometry* 28, 289–304. doi: 10.2307/2786027

Attneave, F., and Curlee, T. E. (1983). Locational representation in imagery: a moving spot task. *J. Exp. Psychol. Hum. Percept. Perform.* 9, 20–30. doi: 10.1037/0096-1523.9.1.20

Baddeley, A. D. (1986). *Working Memory*. Oxford: Oxford University Press.

Baddeley, A. D., and Hitch, G. J. (1974). "Working memory," in *Recent Advances in Learning and Motivation*, Vol. 8, ed. G. A. Bower (New York: Academic Press), 47–89.

Beattie, G. W. (1981). A further investigation of the cognitive interference hypothesis of gaze patterns during conversation. *Br. J. Soc. Psychol.* 20, 243–148. doi: 10.1111/j.2044-8309.1981.tb00493.x

Brooks, L. (1968). Spatial and verbal components in the act of recall. *Can. J. Psychol.* 22, 349–368. doi: 10.1037/h0082775

Caruso, E., and Gino, F. (2011). Blind ethics: closing one's eyes polarizes moral judgments and discourages dishonest behavior. *Cognition* 118, 280–285. doi: 10.1016/j.cognition.2010.11.008

Corsi, P. M. (1972). Human memory and the medial temporal region of the brain. *Dissert. Abstracts Int.* 34, 891B.

Diwadkar, V. A., Carpenter, P. A., and Just, M. A. (2000). Collaborative activity between parietal and dorsolateral prefrontal cortex in dynamic spatial working memory revealed by fMRI. *Neuroimage* 12, 85–99. doi: 10.1006/nimg.2000.0586

Doherty-Sneddon, G., Bonner, L., and Bruce. (2001). Cognitive demands of face monitoring: evidence for visuospatial overload. *Mem. Cognit.* 29, 909–919. doi: 10.3758/BF03195753

Doherty-Sneddon, G., Bruce, V., Bonner, L., Longbotham, S., and Doyle, C. (2002). Development of gaze aversion as disengagement from visual information. *Dev. Psychol.* 38, 438–445. doi: 10.1037/0012-1649.38.3.438

Doherty-Sneddon, G., McAuley, S., Bruce, V., Langton, S., Blokland, A., and Anderson, A. H. (2000). Visual signals and children's communication: negative effects on task outcome. *Br. J. Dev. Psychol.* 18, 595–608. doi: 10.1348/026151000165878

Doherty-Sneddon, G., and Phelps, F. G. (2005). Gaze aversion: a response to cognitive or social difficulty? *Mem. Cognit.* 33, 727–733. doi: 10.3758/BF03195338

Ehrlichman, H. (1981). From gaze aversion to eye-movement suppression: an investigation of the cognitive interference explanation of gaze patterns during conversation. *Br. J. Soc. Psychol.* 20, 233–241. doi: 10.1111/j.2044-8309.1981.tb00492.x

Einav, S., and Hood, B. M. (2008). Tell-tale eyes: children's attribute of gaze aversion as a lying cue. *Dev. Psychol.* 44, 1655–1667. doi: 10.1037/a0013299

Fiore, F., Borella, E., Mammarella, I. C., and Cornoldi, C. (2011). Mental imagery in a visuospatial working memory task and modulation of activation. *J. Cogn. Psychol.* 23, 52–59. doi: 10.1080/20445911.2011.454497

Frischen, A., Bayliss, A. P., and Tipper, S. P. (2007). Gaze cueing of attention: visual attention, social cognition, and individual differences. *Psychol. Bull.* 133, 694–724. doi: 10.1037/0033-2909.133.4.694

Glenberg, A. M. (1997). What memory is for. *Behav. Brain Sci.* 20, 1–55.

Glenberg, A. M., Schroeder, J. L., and Robertson, D. A. (1998). Averting the gaze disengages the environment and facilitates remembering. *Mem. Cognit.* 26, 651–658. doi: 10.3758/BF03211385

Hietanen, J. K., Leppanen, J. M., Peltola, M. J., Linna-Aho, K., and Ruuhiala, H. J. (2008). Seeing direct and averted gaze activates the approach-avoidance motivational brain systems. *Neuropsychologia* 46, 2423–2430. doi: 10.1016/j.neuropsychologia.2008.02.029

Itier, R. J., and Batty, M. (2009). Neural bases of eye and gaze processing: the core of social cognition. *Neurosci. Biobehav. Rev.* 33, 843–863. doi: 10.1016/j.neubiorev.2009.02.004

Jonides, J., Kahn, R., and Rozin, P. (1975). Imagery instructions improve memory in blind subjects. *Bull. Psychon. Soc.* 5, 424–426. doi: 10.3758/BF03333288

Kendon, A. (1967). Some functions of gaze direction in social interaction. *Acta Psychol.* 26, 22–63. doi: 10.1016/0001-6918(67)90005-4

Kerr, N. H. (1987). Locational representation in imagery: the third dimension. *Mem. Cognit.* 15, 521–530. doi: 10.3758/BF03198387

Kerr, N. H. (1993). Rate of imagery processing in two versus three dimensions. *Mem. Cognit.* 21, 467–476. doi: 10.3758/BF03197178

Kleinke, C. L. (1986). Gaze and eye contact: a research review. *Psychol. Bull.* 100, 78–100. doi: 10.1037/0033-2909.100.1.78

Larsen, R. J., and Shackelford, T. K. (1996). Gaze avoidance: personality and social judgments of people who avoid direct face-to-face contact. *Pers. Individ. Dif.* 21, 907–917. doi: 10.1016/S0191-8869(96)00148-1

Lyon, D. R., Gunzelmann, G., and Gluck, K. E. (2008). A computational model of spatial visualization capacity. *Cogn. Psychol.* 57, 122–152. doi: 10.1016/j.cogpsych.2007.12.003

Mann, S., Vrij, A., and Bull, R. (2002). Suspects, lies, and videotape: an analysis of authentic high-task liars. *Law Hum. Behav.* 26, 365–376. doi: 10.1023/A:1015332606792

Markson, L., and Paterson, K. B. (2009). Effects of gaze aversion on visual-spatial imagination. *Br. J. Psychol.* 100, 553–563. doi: 10.1348/000712608X371762

Moukheiber, A., Rautureau, G., Perez-Diaz, F., Jouvent, R., and Pelissolo, A. (2012). Gaze behaviour in social blushers. *Psychiatry Res.* 200, 614–619. doi: 10.1016/j.psychres.2012.07.017

Paivio, A. (1969). Mental imagery in associative learning and memory. *Psychol. Rev.* 76, 241–263. doi: 10.1037/h0027272

Paivio, A. (1971). Imagery and deep structure in the recall of English nominalizations. *J. Verbal Learning Verbal Behav.* 10, 1–12. doi: 10.1016/S0022-5371(71)80086-5

Perfect, T. J., Andrade, J., and Eagan, I. (2011). Eye closure reduces the cross-modal memory impairment caused by auditory distraction. *J. Exp. Psychol. Learn. Mem. Cogn.* 37, 1008–1013. doi: 10.1037/a0022930

Perfect, T. J., Wagstaff, G. F., Moore, D., Andrews, B., Cleveland, V., Newcombe, S., et al. (2008). How can we help witnesses to remember more? It's an (eyes) open and shut case. *Law Hum. Behav.* 32, 314–324. doi: 10.1007/s10979-007-9109-5

Phelps, F. G., Doherty-Sneddon, G., and Warnock, H. (2005). Helping children think: gaze aversion and teaching. *Br. J. Dev. Psychol.* 24, 577–588. doi: 10.1348/026151005X49872

Pönkänen, L. M., Alhoniemi, A., Leppänen, J. M., and Hietanen, J. K. (2011). Does it make a difference if I have an eye contact with you or with your picture? An ERP study. *Soc. Cogn. Affect. Neurosci.* 6, 486–494. doi: 10.1093/scan/nsq068

Siegel, S., and Castellan, N. J. (1988). *Nonparametric Statistics for the Behavioral Sciences*, 2nd Edn. New York, NY: McGraw-Hill.

Vredeveldt, A., Baddeley, A. D., and Hitch, G. J. (2012). The effects of eye-closure and "ear-closure" on recall of visual and auditory aspects of a criminal event. *Eur. J. Psychol.* 8, 284–299. doi: 10.5964/ejop.v8i2.472

Vredeveldt, A., Baddeley, A. D., and Hitch, G. J. (2013). The effectiveness of eye-closure in repeated interviews. *Leg. Criminol. Psychol.* doi: 10.1111/lcrp.12013 [Epub ahead of print].

Vredeveldt, A., Hitch, G. J., and Baddeley, A. D. (2011). Eye-closure helps memory by reducing cognitive load and enhancing visualisation. *Mem. Cognit.* 39, 1253–1263. doi: 10.3758/s13421-011-0098-8

Vredeveldt, A., and Penrod, S. D. (2013). Eye-closure improves memory for a witnessed event under naturalistic conditions. *Psychol. Crime Law* 19, 893–905. doi: 10.1080/1068316X.2012.700313

Vrij, A., and Semin, G. R. (1996). Lie experts' beliefs about nonverbal indicators of deception. *J. Nonverbal Behav.* 20, 65–80. doi: 10.1007/BF02248715

Wagstaff, G. F., Brunas-Wagstaff, J., Cole, J., Knapton, L., Winterbottom, J., Crean, V., et al. (2004). Facilitating memory with hypnosis, focused meditation, and eye closure. *Int. J. Clin. Exp. Hypnosis* 52, 434–455. doi: 10.1080/00207140490889062

Wais, P. E., Rubens, M. T., Boccanfuso, J., and Gazzaley, A. (2010). Neural mechanisms underlying the impact of visual distraction on retrieval of long-term memory. *J. Neurosci.* 30, 8541–8550. doi: 10.1523/JNEUROSCI.1478-10.2010

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Distraction during learning with hypermedia: difficult tasks help to keep task goals on track

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In educational hypermedia environments, students are often confronted with potential sources of distraction arising from additional information that, albeit interesting, is unrelated to their current task goal. The paper investigates the conditions under which distraction occurs and hampers performance. Based on theories of volitional action control it was hypothesized that interesting information, especially if related to a pending goal, would interfere with task performance only when working on easy, but not on difficult tasks. In Experiment 1, 66 students learned about probability theory using worked examples and solved corresponding test problems, whose task difficulty was manipulated. As a second factor, the presence of interesting information unrelated to the primary task was varied. Results showed that students solved more easy than difficult probability problems correctly. However, the presence of interesting, but task-irrelevant information did not interfere with performance. In Experiment 2, 68 students again engaged in example-based learning and problem solving in the presence of task-irrelevant information. Problem-solving difficulty was varied as a first factor. Additionally, the presence of a pending goal related to the task-irrelevant information was manipulated. As expected, problem-solving performance declined when a pending goal was present during working on easy problems, whereas no interference was observed for difficult problems. Moreover, the presence of a pending goal reduced the time on task-relevant information and increased the time on task-irrelevant information while working on easy tasks. However, as revealed by mediation analyses these changes in overt information processing behavior did not explain the decline in problem-solving performance. As an alternative explanation it is suggested that goal conflicts resulting from pending goals claim cognitive resources, which are then no longer available for learning and problem solving.

Keywords: hypermedia, distraction, volitional action control, goal conflicts, pending goal, seductive details

INTRODUCTION

Recent years have seen rapid developments in the use of computer-based learning environments. Many of these environments are based on hypermedia structures, that is, network-like information structures where fragments of information such as text, pictures, or videos are stored in nodes that are interconnected by digital hyperlinks (Conklin, 1987). Hypermedia environments grant users control over their instruction in that they can select information units and choose the point of time as well as the pacing and sequence of presentation according to their goals (Dillon and Jobst, 2005; Scheiter and Gerjets, 2007; Scheiter, 2014). Accordingly, the same hypermedia environment may serve a multitude of different goals that guide information utilization, whereby each information unit can be classified as being more or less relevant with respect to a particular information goal. Accordingly, while pursuing a goal such as to learn about a specific topic or solve a particular problem students may encounter information in a hypermedia environment that is irrelevant to the primary learning or problem-solving goal.

In the current paper we were interested in the effects of information that is irrelevant to the current task, but nevertheless included in the hypermedia environment that is used to accomplish this task. This is a situation that has become omnipresent for many students, who nowadays are often using the Internet as their primary resource for finding information relevant to their educational goals (e.g., for doing their essay assignments, looking up answers to a specific question, etc.; cf. Lenhart et al., 2001). On the one hand, rapid access to a vast amount of information available through the Internet is seen as beneficial because it allows students to come up with a multifaceted mental representation of the content in question; on the other hand, it imposes high cognitive demands on users in terms of evaluating whether a specific piece of information is relevant to the task at hand and of keeping track of the current goal (Braasch et al., 2009). Recent research has shown that students largely vary in their ability to evaluate information relevance, which is predictive of their task performance: successful students have been shown to reflect upon the relevance of the information that they find while browsing the Internet and monitor how well a piece of information will help them to accomplish their educational objective, whereas less successful students appear to be less aware about information relevance when searching the Internet (Braasch et al., 2009; Goldman et al., 2012). The latter students' navigation behavior appears more erratic and less attuned toward the educational goal. This may be because these students are distracted by task-irrelevant, albeit potentially interesting information that they encounter.

Carmel et al. (1992) speak of general purpose browsing when information search is guided by interest. In this case, *transient search goals* are assumed to be formed during browsing that change over time depending on the local context provided in the hypermedia environment (i.e., context-sensitive browsing according to Hirashima et al. (1997). These transient browsing goals may compete with the current primary task for execution. Moreover, the information that is irrelevant to the primary task may even be relevant to other, currently pending tasks that a user is aware of when entering the hypermedia environment. Although there may be sufficient later opportunities to perform these pending tasks (i.e., after having accomplished the primary task), these pending tasks may nevertheless compete with the learning task for being executed (i.e., *pending goals*). Thus, even though students' navigation behavior may sometimes appear erratic, it is goal-driven, but these goals are different from the primary educational goal of finding task-relevant information that will help to solve a learning and problem-solving task.

In the present paper we were interested in the effects of transient as well as pending goals during learning and problem solving with a hypermedia environment. In particular, we studied how such goals would impact students' problem-solving performance as well as their information processing behavior in terms of retrieving and reading information that was either relevant or irrelevant to the primary task. Against the backdrop of theories of volitional action control it was investigated how the difficulty of the primary (learning and problem solving) task would moderate the effects of transient and pending goals, respectively.

TRANSIENT SEARCH GOALS DURING LEARNING AND PROBLEM SOLVING WITH HYPERMEDIA

Presumably everybody who has ever tried finding a specific information on the Internet has made the experience that one may easily get carried away and click on hyperlinks that will provide access to information unrelated to the primary search task. Such a retrieval of additional information is likely to be triggered by interest and curiosity evoked by the hyperlink's label. Carmel et al. (1992) or Hirashima et al. (1997) describe such a behavior as context-sensitive browsing, where a user's information access is guided by interest and transient search goals are formed. These goals are characterized by the fact that they may change rather quickly and be replaced by others depending on the information that is encountered and how well the information is suited to sustain interest. Thus, different from other goals that result from deliberate reasoning about expectancies and values associated with goal attainment, transient search goals are unlikely to have a lasting impact on behavior. Thus, it is not clear whether encountering interesting information and the transient goals that may arise from it will have a pronounced impact in the presence of an already existing learning or problem-solving goal.

Barab et al. (1996) assume that primary goals provide such a strong form of guidance that transient goals are unlikely to emerge. In particular, they assume that instructed or experimentally induced goals "constrain users' searches by removing external degrees of freedom (i.e., searches are not distracted by intention-irrelevant information on each screen)" (p. 387). In their study the experimental group had to choose a problem to be solved with information provided in a hypermedia system, whereas the control group had no specific goal when browsing that system. Comparing the two groups revealed differences in a number of strategic measures of information search and information utilization. Furthermore, higher standard deviations for these navigational measures in the no-goal group suggested that these students were guided by a variety of goals that were formed spontaneously during hypermedia navigation. Thus, whereas users in the no-goal condition seemed to be guided by transient browsing goals, users in the goal-condition focused on the accomplishment of the task that they had selected initially. Thus, according to the findings of Barab and colleagues the presence of potentially interesting, but task-irrelevant information does not appear to be sufficient to yield goals that are sufficiently strong to compete with the primary goal for execution.

On the other hand, research on the seductive details effect suggests that adding interesting, but task-irrelevant information to an instructional message (e.g., decorative illustrations, entertaining text messages) may have a negative effect on learning and problem solving (cf. Goetz and Sadoski, 1995; Harp and Mayer, 1998; Rey, 2012). Various explanations have been proposed for why seductive details hinder learning and problem solving (Harp and Mayer, 1998; Rey, 2012). In particular, seductive details may (a) distract students' attention away from processing task-relevant information toward task-irrelevant information (distraction), (b) trigger inappropriate schemas for encoding the information yielding an erroneous interpretation of it (diversion), (c) interrupt the construction of a coherent mental representation of the relevant information (disruption) or (d) demand cognitive resources which are then no longer available for the main task (depletion). Notably, only the first explanation should be visible in terms of students' information processing behavior, since according to this explanation distracted students should process relevant information less intensively when seductive details are present. Lehman et al. (2007) provided first evidence in line with this assumption: Their students spent less time reading relevant text when seductive details were present compared with when seductive details were absent. However, it is unclear from their study whether this change in information processing behavior was the cause of reduced performance or whether it just coincided with it. Nevertheless, it seems to be a plausible assumption that a less frequent retrieval of task-relevant pages should be associated with lower performance (see Naumann et al., 2007, for similar results during learning with hypermedia). Similarly, a more frequent retrieval of task-irrelevant information should yield reduced performance, especially if learners process this information at the expense of task-relevant information.

Based on the results on the seductive details effect, we assumed that the additional presentation of interesting, but task-irrelevant information in a learning and problem solving hypermedia environment would interfere with the primary problem-solving task. In particular, students were expected to show worse problem-solving performance and to process the interesting information at the expense of task-relevant information.

It is important to note however that our experimental setting differed from the settings in which the seductive details effect has been observed in how the irrelevant information was presented. In hypermedia environments, users commonly have to actively select the irrelevant information by clicking on a respective link, whereas the seductive details effect has been found when irrelevant information was presented on the same page as the relevant contents. As a consequence, negative effects of presenting interesting information in a hypermedia environment may be subtler than the ones usually found in seductive details research, where it is almost impossible to ignore the irrelevant information. On the other hand, providing interesting information in additional hypermedia nodes allowed us to register the time spent processing this information in a very parsimonious way by analyzing students' log files.

The impact of presenting interesting, but task-irrelevant information, which would presumably lead to the formation of transient browsing goals, was studied in Experiment 1 of the present paper. In Experiment 2, we studied how a pending goal would affect hypermedia-based learning and problem solving.

PENDING SEARCH GOALS DURING LEARNING AND PROBLEM SOLVING WITH HYPERMEDIA

Pending goals in hypermedia-based learning and problem solving may arise if the user knows that s/he will have to perform a second task later on that is related to the information that is irrelevant to the primary task. That is, in contrast to transient goals pending goals are not spontaneously formed but already exist when a user starts working on a learning and problem-solving task. Pending goals may absorb cognitive resources needed for keeping them active until task pursuit and they may compete with the current learning and problem-solving goal for execution. There are findings from research on prospective memory demonstrating that pending goals reside in memory with a heightened state of activation (Goschke and Kuhl, 1993; Marsh et al., 1999). As a consequence of their specific status in memory, representations of prospective tasks will be activated very easily by related external cues (cf. Altmann and Trafton, 2002), which in turn may lead to interference, distraction, intrusion errors, and resource costs (cf. Li et al., 2000). Thus, when encountering information that is relevant to a pending task in a hypermedia environment, this information will be perceived as a good opportunity to engage in activities related to the accomplishment of the pending goal—even in situations where ample opportunity exists to postpone this task until the primary task has been completed.

Goal conflicts such as conflicts between pending goals and primary goals have been studied against the backdrop of theories on volitional action control (e.g., Heise et al., 1994b, 1997). In the context of learning and motivation, volitional action control refers to questions of how resources are allocated and managed during goal pursuit, how protective actions are taken toward goals, and how students cope with internal and external distractions (Corno and Kanfer, 1993). Volitional action control becomes especially important when "academic goals require sustained effort in the face of distractions and competing goals" (Corno and Kanfer, 1993, p. 305). One advantage of conceptualizing the present research against theories of volitional action control is that it allows to state more precisely the conditions under which pending goals (and possibly also transient goals) are most likely to have an impact on a primary task by causing distraction. In particular, theories of volitional action control suggest that goal competition will have less negative impact on a primary task, if the primary task is relatively difficult to accomplish.

TASK DIFFICULTY AS A MODERATOR

According to theories of volitional action control, an enhanced task difficulty of the primary goal leads to an increased level of effort that reduces distraction effects. In models of volitional action control this difficulty-related effort investment is interpreted as a volitional process that helps to maintain the current goal in the face of difficulties and to protect it against competing goals (cf. Kuhl, 1984; Gollwitzer, 1990; Corno, 1993; Heise et al., 1994a; Goschke, 2003). In line with this assumption it has been shown that distraction effects due to goal competition (as measured by impaired performance in a word-classification task) were stronger for easy tasks than for more difficult tasks (Heise et al., 1994b, 1997). Analogously, Czerwinski et al. (2000a,b) have demonstrated that instant messaging during computer-based information-search tasks resulted in performance impairments with respect to the search task, whereby these effects were moderated by the task relevance of the messages, the difficulty of the search task, and the search task's degree of completion at the time the distraction occurs.

Based on theories of volitional action control and the aforementioned findings we predicted that a pending goal related to interesting, but task-irrelevant information in a hypermedia environment would have a stronger negative impact on current task performance if the current task was easy rather than more difficult. Analogously, because a higher difficulty of the task should serve to prevent distraction, there should be less processing of task-irrelevant information at the expense of task-relevant processing when students work on more difficult tasks. Since we were interested in whether task difficulty would also moderate the effects of transient goals, the difficulty of the primary task was used as an independent variable in both experiments.

OVERVIEW OF EXPERIMENTS AND HYPOTHESES

In the present paper two experiments are reported which investigated how interesting, but task-irrelevant information would affect learning and problem solving in a hypermedia environment. In Experiment 1, interesting, task-irrelevant information was added under the assumption that students would form transient search goals regarding this information, which would then interfere with the primary goal of problem solving. In Experiment 2, students were also asked to carry out a search task regarding the interesting information, which they would have to work on after they had accomplished the primary problem-solving task. This instruction was assumed to lead to the formation of a pending goal lingering in memory while working on the problem-solving task.

According to Hypothesis 1, a transient goal as well as a pending goal related to interesting, but task-irrelevant information were assumed to lead to worse problem-solving performance than the presence of either no task-irrelevant information or less interesting information. Based on theories of volitional action control this effect was assumed to be visible only if the problem-solving task was rather easy, but not when it was more difficult.

According to Hypothesis 2, a transient goal as well as a pending goal were expected to lead to (more) time being spent on the processing of the task-irrelevant information (Hypothesis 2a) as well as to less time being spent on the processing of the task-relevant information (Hypothesis 2b).

According to Hypothesis 3, it was assumed that the negative effects of conflicting goals on problem-solving performance described in Hypothesis 1 would be mediated by the changes in information processing behavior described in Hypothesis 2.

EXPERIMENT 1

This experiment aimed at testing whether giving learners the opportunity to retrieve interesting, but task-irrelevant information—thereby stimulating the formation of transient browsing goals—would adversely affect problem-solving performance. Negative effects of adding interesting, but task-irrelevant information were expected to be visible when working on an easy version of a problem-solving task, but not when working on a more difficult version. Moreover, it was expected that in the condition with an easy compared with a more difficult problem-solving task students would spend more time processing the interesting, task-irrelevant information, while at the same time processing task-relevant information to a lesser extent.

MATERIALS AND METHODS

Participants and design

Sixty-six students (43 female, 23 male) of the University of Goettingen, Germany, participated in the experiment for either course credit or payment. Their average age was 24.94 years ($SD = 3.95$). Participation was voluntary. All participants had taken a course in introductory statistics and were therefore familiar with the domain chosen for experimentation, that is, probability theory. The study was based on a between-subjects 2×2-design with task difficulty (easy vs. difficult) and presence of task-irrelevant, but interesting information (with vs. without) as independent variables. Students were randomly assigned to one of the four experimental conditions with 17 participants serving in each of the two conditions containing additional interesting information and 16 participants serving in each of the two control conditions.

Materials

In the present studies we used a learning and problem-solving hypermedia environment on combinatorics called HyperComb. It conveys knowledge on how to calculate the number of possible arrangements or selections of elements as a prerequisite for determining the probability of complex events. The present version of HyperComb consisted of a short introduction to the domain of combinatorics where participants were instructed that they would have to solve three probability word problems. They were trained to use a multiple-choice form that they later needed for solving the test problems. The participants were further told that the worked-out examples, which would be used in order to convey information on different problem categories, would be available during the whole experiment (i.e., also during solving the test problems).

At the end of the introduction three word problems were presented on a single screen and one of them had to be selected to begin with. A navigation bar at the margin of the screen contained links to the worked examples as well as to the test problems and was accessible during the whole experiment. There was no formal distinction between a learning and a problem-solving phase in this environment. Rather, information necessary to solve the test problems could be retrieved during the whole course of the experiment. The test problems' difficulty depended on experimental condition (**Table 1**). In accordance with preliminary studies we manipulated their difficulty by using smaller numbers in the easy test problems and by stating them in a more familiar way than the difficult problems. Inspired by Ross and Kilbane (1997) in the easy test problems typical roles were assigned to the objects mentioned (e.g., knights choosing horses), whereas in the difficult problems reversed roles were assigned to the respective objects (e.g., horses choosing knights). The structural features of the test problems and thus their solution procedure were not affected by this manipulation of difficulty. Participants had to solve the problems by marking the correct problem category in a solution form, where the six problem categories were represented by their appropriate solution formulas. Additionally, participants had to specify the correct value for two variables out of a set of five alternatives, respectively.

Each of the six problem categories was illustrated by one worked-out example embedded in an interesting cover story related to issues of attractiveness and mate choice (see **Table 2**). Each worked-out example was presented on two separate pages. The first page contained the problem statement and a hyperlink referring to its solution. The solution page explained the structural features of the respective problem category, the appropriate solution formula, and its application to the example problem. Depending on experimental condition additional hyperlinks were embedded in each of the example problems that referred to interesting, but task-irrelevant information. The condition without additional interesting information (control condition) comprised only relevant information (i.e., the test problems and worked-out examples for the six problem categories) and consisted of 27 pages. In the condition with additional interesting information each worked-out example page was linked to one page with potentially interesting, but task-irrelevant information on attractiveness and mate choice. For instance, the top-200-list hyperlink in **Table 2** referred to a list of billionaires, which was considered to be of personal interest to the learners. These pages that were directly linked to the worked-out examples were termed first-order irrelevant information pages. Additionally, we introduced second-order irrelevant information pages that could be retrieved by clicking hyperlinks embedded in first-order

Table 1 | Test problems.

Angler problem: A club of vegetarian anglers has four (24) members. All vegetarian anglers have committed themselves to throw the fish they catch *directly* back into the lake (at the end of the day.). One day the club members, one after another, go fishing at a lake that is 8 (812) square meters in size and has five (220) fish in it: one (17) zander, one eel, one trout, one (200) pike(s) and one carp. *In the order of their age, all club members catch one fish.* (First, the eel bites into a hook. The angler throws the eel into a pail and continues fishing. Second, the trout catches the bait.) How do you calculate the probability of the oldest angler catching the eel and the second oldest catching the trout?

Dog problem: An animal home currently hosts 11 (81) dogs. 4 (14) of them are terriers, the remaining (67) are half-breeds. 2 (22) blond and 4 (14) brunette children come to the animal home wanting dogs as pets. To prevent the children from arguing over whom gets which dog, *the director asks the children to draw lots. First, the brunette children draw the lots, one each.* (the dogs are distributed by random. The name of each child is written on a dog biscuit, which are taken out of a bowl by the dogs. First, each of the terriers gets to choose one dog biscuit.) How do you calculate the probability of every brunette child getting a terrier?

Knight problem: 10 (110) knights participate in the 9th king's tournament. The king provides the tournament with 12 (122) horses. (that are able to talk by means of a magic potion. The horses start to pick the knights blindfold. The biggest horse gets to pick first, then the second biggest and so on.) *The knights have to pick their horses blindfold. The heaviest knight gets to pick first, then the second heaviest and so on.* How do you calculate the probability of the heaviest knight getting the biggest horse, the second heaviest knight getting the second biggest horse, and the third heaviest knight getting the third biggest horse?

Text portions in italics were part of the problem statements for the easy versions only, whereas text portions in parentheses were used only in the difficult problems.

Table 2 | Worked-out example for the problem category "combination without replacement."

Example problem:
Financial resources seem to be a key factor in mate choice, especially for women. Thus, it may be of interest that in the current top-200 list of the business magazine "Forbes" the 200 wealthiest people in the world are ranked by the sizes of their fortunes. What is the probability of selecting the 5 wealthiest persons out of this set of 200 people at random?
Please imagine this problem situation as well as possible and try to find a solution to the problem. When you have thought about the solution to this example problem please compare the solution that you have considered for this problem with this example solution.

Example solution:
Combination problems are about the number of possibilities for selecting a subset of elements out of a set of elements without regard to the order in which they are selected ("*combination*s"). If no element can appear more than once in the selected subset, the problem is of the type combination without replacement.
The number A of possible combinations without replacement can be calculated by using the following formula:
$A = n!/(n - k)!k!$
n is the number of elements in a set that can be selected, k is the subset of selected elements and $n! = n*(n - 1)*(n - 2)...*1$.
The given example is about a selection out of a set of 200 persons (the top-200 list). This is the set of elements for selection ($n = 200$). The question asks the probability of randomly selecting the 5 richest persons out of this list, whereby the order of selecting the 5 persons is irrelevant. Therefore, the number of selected persons equals $k = 5$.
Inserting these values into the formula for combination without replacement, that is $A = n!/(n - -k)!k!$, yields 200! / (200-5)! 5! = 2,535,650,040 combinations.
Thus the probability for one of these combinations (selecting the 5 wealthiest persons) equals 1/2,535,650,040 = 0.000000039%.

Hyperlinks are underlined. The example problem and its solution were presented on separated pages.

irrelevant information pages. Choosing first-order and second-order irrelevant information pages was interpreted as an active retrieval of irrelevant information. The condition with interesting information contained 18 additional first-order and second-order irrelevant pages (i.e., three irrelevant information pages for each worked-out example).

Dependent variables

As dependent measures we registered students' problem-solving performance, time on relevant information pages (i.e., worked-out examples and test problems) as well as time on actively retrieved irrelevant information in the condition with interesting information. For each of the three word problems the participants had to mark the correct problem category and values for the two variables in a multiple-choice form. One point was assigned for each correct answer so that a maximum of nine points was possible. The sum across all three problems was transformed into a percentage for easier interpretation. The time on relevant information pages as well as on task-irrelevant pages were recorded in seconds based on the log file data.

Procedure

Students were tested individually. After a short introduction to HyperComb, students entered the learning and problem-solving section of the environment. They were told that they could work through it at their own pace and go back and forth between information pages as they wished. There were no time limitations for the experiment. However, participants were told to work as quickly and as correctly as possible. Participants were told that in principle all information available might be helpful for solving the word problems. A single session lasted about 60 min.

Data Analyses

In order to test the interaction hypotheses for problem-solving performance and time on relevant information we used regression analyses along with effect coding (cf. Abelson and Prentice, 1997; Niedenthal et al., 2002) since this captured our directional hypotheses most adequately. The basic idea behind contrast coding is to test whether a specific model ("focal contrast"), which is based on the hypothesized relative group differences, better fits the observed data than a number of independent (i.e., orthogonal), alternative models ("residual contrasts"). These residual contrasts are not necessarily meaningful in the sense that they represent alternative theoretical assumptions, but are defined according to formal requirements. If the focal contrast fits the data to a significant degree while the residual contrasts do not, it can be concluded that the hypothesized pattern of group differences describes the observed data accurately. If the focal contrast does not fit the data while the residual contrasts do, then the data do not conform to the hypotheses and are better explained by other models. If both the focal contrasts and the residual contrasts fit the model significantly, then the hypothesized group differences can be found in the data but the data are additionally explained by other patterns of relative group differences. In effect coding, the relative differences of codes are meaningful. A coding of 0 represents the grand mean of the observed data, whereas codings of either under or over 0 represent relative deviations from the grand mean. Positive effect codes mean that the condition that has been assigned the code is expected to score above the grand mean, whereas a negative code means that the condition is expected to score below the grand mean.

Since there were four different groups in this experiment, three contrasts needed to be tested to fully account for all degrees of freedom (see **Table 3** for the focal and residual contrasts).

According to our main interaction hypothesis (Hypothesis 1), the presence of additional interesting information should lead to a reduction in problem-solving performance compared with the control condition when working on easy problems, but not when working on difficult problems. Accordingly, in the focal contrast the condition with easy test problems and no additional information was assumed to score best (coded +3), whereas the remaining three conditions were assumed to show worse performance (each coded −1)—either because of the higher difficulty of the problems or because the students were given the opportunity to retrieve interesting information while working on easy problems.

According to Hypothesis 2, participants in the condition with easy test problems and with additional interesting information should spend the least time on relevant information pages (coded −3), whereas more time on these pages should be spent in each of the remaining conditions (each coded +1). Moreover, these participants should also spend more time on task-irrelevant information. Since there was no irrelevant information in the control condition, this was tested by comparing the two conditions with interesting information regarding the time students spent on this information with a *t*-test. If students were more vulnerable to distraction when solving easy compared with more difficult problems, then they should also process more of the irrelevant information in the prior than in the latter case.

Finally, mediation analyses (Preacher and Hayes, 2008) were planned to test whether changes in information processing behavior can explain differences in problem-solving performance (Hypothesis 3). In this analysis the total effect that the presence of task-irrelevant information has on problem-solving performance can be separated into the indirect effect that is mediated by the changes in information processing behavior and the remaining direct effect that cannot be explained by the mediating processing variables. A significant indirect effect and a non-significant direct effect would indicate that changes in the time spent on processing task-relevant and/or task-irrelevant information can explain a reduction in problem-solving performance when working on easy problems while additional interesting information is present.

Table 3 | Contrast coding for Experiments 1, 2.

Goal condition	Experiment 1: interesting, task-irrelevant information/Experiment 2: pending goal			
	Without		With	
Task difficulty	Easy	Difficult	Easy	Difficult
PROBLEM-SOLVING PERFORMANCE				
Focal contrast	+3	−1	−1	−1
Residual contrast 1	0	−1	2	−1
Residual contrast 2	0	1	0	−1
TIME ON TASK−RELEVANT INFORMATION				
Focal contrast	+1	+1	−3	+1
Residual contrast 1	−2	+1	0	+1
Residual contrast 2	0	−1	0	+1
TIME ON TASK−IRRELEVANT INFORMATION				
Focal contrast	−1	−1	+3	−1
Residual contrast 1	−1	−1	0	+2
Residual contrast 2	+1	−1	0	0

RESULTS AND DISCUSSION

Results

Means and standard deviations are displayed in **Table 4**.

In a first step, problem-solving performance was analyzed by means of a regression analysis in which the focal contrast and the two residual contrasts described earlier were entered simultaneously as predictors. The overall regression model was marginally significant only, $R^2 = 0.11$, $F_{(3, 62)} = 2.70$, MSE = 382.48, $p = 0.055$. The results for the single predictors revealed that neither the focal contrast nor the second residual contrast explained variance to a sufficient degree (focal contrast: $\beta = 0.20$, $p = 0.10$; second residual contrast: $\beta = -0.03$, $p = 0.83$); however, the first residual contrast did, $\beta = 0.27$, $p = 0.03$. This latter contrast reflects the main effect of task difficulty, that is, students working on more difficult problems solved fewer problems correctly than those working on easier problems.

Secondly, the time on relevant information pages was analyzed by means of a regression analysis in which the focal contrast and the two residual contrasts described earlier were entered simultaneously as predictors. Because this variable was not normally distributed, we used the logarithmized (ln) values for the analysis.

Table 4 | Means (and standard deviations) as a function of interesting, task-irrelevant information and task difficulty (Experiment 1).

	Interesting, task-irrelevant information			
	Without		With	
Task difficulty	Easy	Difficult	Easy	Difficult
Problem-solving performance in % correct	75.23 (14.98)	60.65 (20.46)	74.73 (21.16)	62.09 (20.77)
Time on task-relevant information in seconds	1310.25 (418.24)	1473.88 (411.45)	1366.18 (527.87)	1317.18 (303.09)
Time on task-irrelevant information in seconds	–	–	22.12 (45.73)	111.71 (150.56)

The overall regression model was not significant, $F < 1$. Thus, there were no differences in the time spent processing relevant information across the four experimental conditions.

Thirdly, we had a closer look at the time on task-irrelevant information in the two conditions where this information had been available. In the condition with easy problems, 41.2% of the students had retrieved additional information at least once for at least 12 s and at most 185 s. In the condition with more difficult problems, 52.9% of the students had retrieved additional information at least once for at least 33 s and at most 607 s. A t-test revealed marginally significant differences between the two conditions, $t_{(17.652)} = -1.79$, $p = 0.09$, which became significant when analyzing only the (logarithmized) data for those students who had retrieved interesting information, $t_{(14)} = -2.20$, $p = 0.045$. Importantly, in contrast to our hypothesis, students working on more difficult problems tended to process task-irrelevant information for a longer time than students working on easier problems. However, it is important to bear in mind that these findings reliably hold only for less than half of the sample investigated.

Because there had been no evidence for negative effects of interesting, task-irrelevant information on either problem-solving performance or time on relevant information as well as differences in processing task-irrelevant information in contrast to our initial assumption, we refrained from running the mediation analyses described above.

Discussion

The results showed that adding interesting, but task-irrelevant information was suited to evoke students' interest—at least in some of them. In particular, students who had to solve difficult test problems were slightly more prone to take the bait and to retrieve and process the irrelevant information. This finding stands in contrast to what would have been predicted based on volitional action control theory. According to this theory more difficult tasks should serve to protect the main goal (i.e., learning and problem solving) from distractions that arise during task accomplishment, whereas students working on easier problems should be more vulnerable to engage in off-task activities.

It is important to note that students in the present experiment even though they processed task-irrelevant information showed no performance decrements. Thus, the opportunity to form transient browsing goals did not affect students' problem-solving performance nor did it lead to less processing of task-relevant information. To conclude, transient browsing goals even though they may lead to observable off-task behavior may not be strong enough to lead to visible aversive effects regarding performance. Thus, students were able to keep their task goal on track.

In Experiment 2 we investigated whether this pattern of results would change if the task-irrelevant information was related to a pending task that had to be accomplished subsequently to the learning and problem-solving task.

EXPERIMENT 2

In this experiment we investigated whether pending goals that arise from tasks that have to be accomplished subsequently to completing the primary task compete with the latter goal for execution. Based on models of volitional action control we predicted that effects of goal competition would be observable and would be moderated by the primary task's difficulty (Heise et al., 1997; Czerwinski et al., 2000a,b). That is, we expected that problem-solving performance would be impaired due to pending goals for students working on easy problem-solving tasks, but not for those solving more difficult test problems. Moreover, performance impairments were assumed to be associated with and potentially caused by less time spent on processing task-relevant information and more time spent on processing task-irrelevant information, respectively.

MATERIALS AND METHODS

Participants and design

Sixty-eight students (41 female, 27 male) of the University of Goettingen, Germany, participated in the experiment for either course credit or payment. Average age was 24.75 years ($SD = 4.87$). Participation was voluntary. All participants had taken a course in introductory statistics and were therefore familiar with the domain chosen for experimentation. The study was based on a between-subjects 2 × 2-design with task difficulty (easy vs. difficult) and presence of pending goal related to interesting, task-irrelevant information (with vs. without) as independent variables. Seventeen students were randomly assigned to each of the four experimental conditions.

Materials

The same hypermedia environment on combinatorics as in Experiment 1 was used for experimentation. HYPERCOMB consisted of a short introduction to the domain and a learning and problem-solving phase, which comprised three test problems as well as one worked-out example for illustrating each of the six problem categories. As in Experiment 1, depending on experimental condition the test problems were either easy or more difficult to solve. The worked-out examples were embedded in interesting cover stories related to issues of attractiveness and mate choice. In all versions of the environment, hyperlinks were embedded in the example problem that allowed for retrieving additional information. The interestingness and the relevance of this information for the pending goal depended on experimental condition. In *conditions with pending goal* interesting, task-irrelevant information was linked to the worked-out examples, which was identical to the respective condition of Experiment 1. Additionally, to induce a pending goal participants were informed that they would have to work on a second task within the same hypermedia environment after having finished the problem-solving task. This second task consisted in answering three questions about attractiveness and mate choice that were presented at the beginning of the experiment (e.g., which eight factors are most important in influencing mate choice?). Participants were instructed to work on the problem-solving task first and to postpone thinking about the question-answering task until they had finished the word problems. They were assured that they would have enough time afterwards to browse the hypermedia environment for information relevant to this second task. Because the information on attractiveness and mate choice was of relevance to this explicit second task it provided an opportunity for participants to execute activities related to the pending question-answering task. In the condition *without pending goal* definitions of legal terms (e.g., proof, investigation, procedure) were linked to the worked examples. This information was supposed to be of no great interest to the learners. It was used since on the one hand we wanted to avoid the formation of transient browsing goals, while on the other hand ensuring that the hypermedia environment contained the same amount of task-irrelevant information as in the pending-goal condition. Participants were instructed to work on the learning and problem-solving task and no second task was announced to them.

Dependent variables

Students' problem-solving performance, the time spent processing relevant information pages as well as the time spent on irrelevant information pages were assessed in the same manner as in Experiment 1.

Procedure

The procedure was identical to that of Experiment 1 with one exception. In the conditions with pending goal, students were told that they would have to work on a second task after having finished the primary task before they started working on the test problems.

Data analyses

The data were analyzed using regression analyses along with effect coding and mediation analyses analogously to Experiment 1. The focal and residual contrasts for the regression analyses are shown in **Table 3**.

RESULTS AND DISCUSSION

Results

Means and standard deviations are displayed in **Table 5**.

In a first step, problem-solving performance was analyzed by means of a regression analysis in which the focal contrast and the two residual contrasts were entered simultaneously as predictors. The overall regression model was significant, $R^2 = 0.14$, $F_{(3,\ 64)} = 3.50$, MSE $= 353.32$, $p = 0.02$. The results for the single predictors revealed that only the focal contrast was a significant predictor, $\beta = 0.37$, $p = 0.002$ (first residual contrast: $\beta < 0.01$, $p > 0.99$; second residual contrast: $\beta = 0.03$, $p = 0.79$). Accordingly, as expected, students working on easy problems without pending goal achieved the best problem-solving performance. Students working on easy problems with pending goal, however, showed a similar performance as students working on more difficult problems.

Secondly, the time spent on relevant information pages was analyzed. Because this variable was not normally distributed, we used the logarithmized (ln) values for the analysis. The overall regression model was significant, $R^2 = 0.13$, $F_{(3,\ 64)} = 3.25$, MSE $= 0.20$, $p = 0.03$. This effect could be traced back completely to the variance being explained by the focal contrast, $\beta = 0.31$, $p = 0.01$ (first residual contrast: $\beta = -0.17$, $p = 0.15$; second residual contrast: $\beta = 0.09$, $p = 0.46$). Accordingly, students working on easy problems when a pending goal was present spent less time processing task-relevant information pages compared with the remaining conditions.

Thirdly, we analyzed the time on task-irrelevant information. There were only relatively few students in each condition, who had actively retrieved additional irrelevant information, whereby those who did differed largely in the time spent processing this information: with pending goal—easy problems: 29.4% of students, min. duration: 57 s, max. duration: 803 s; with pending goal—difficult problems: 29.4% of students, min. duration: 14 s, max. duration: 248 s; without pending goal—easy problems: 29.4% of students, min. duration: 4 s, max. duration: 18 s; without pending goal—difficult problems: 41.2% of students, min. duration: 4 s, max. duration: 53 s). Despite differences in the variance among conditions, we analyzed the time on irrelevant information by means of a regression assuming that this analysis is sufficiently robust against violations of homogeneity assumptions. The regression revealed a marginally significant overall model, $R^2 = 0.33$, $F_{(3,\ 64)} = 2.66$, MSE $= 1442.52$, $p = 0.055$. This effect could be traced back completely to the variance being explained by the focal contrast, $\beta = 0.32$, $p = 0.009$ (first residual contrast: $\beta = 0.10$, $p = 0.41$; second residual contrast: $\beta = -0.01$, $p = 0.91$). Accordingly, students working on easy problems when a pending goal was present spent more time processing task-irrelevant information pages compared with the remaining conditions. However, it is important to note that this effect was driven by a small subgroup of students, whereas most participants did not retrieve any of the task-irrelevant information at all.

To summarize, in line with predictions derived from volitional action control theory students solving easy problems when a pending goal related to interesting information was present solved less problems correctly, processed task-relevant information for a shorter time and task-irrelevant information for a longer time compared with the remaining conditions. This raises the issue whether the latter changes in overt information processing behavior can be used to explain the negative effects found for problem-solving performance. To answer this question, we had a closer look at only the two conditions with easy test problems and

Table 5 | Means (and standard deviations) as a function of a pending goal related to interesting, task-irrelevant information and task difficulty (Experiment 2).

Task difficulty	Pending goal			
	Without		With	
	Easy	Difficult	Easy	Difficult
Problem-solving performance in % correct	77.78 (11.03)	61.66 (19.64)	60.78 (21.87)	59.91 (20.67)
Time on task-relevant information in seconds	1469.12 (633.70)	1226.06 (379.85)	950.24 (429.49)	1211.76 (916.13)
Time on task-irrelevant information in seconds	2.18 (4.59)	7.06 (14.35)	105.29 (228.76)	34.47 (71.80)

ran two mediation analyses. Condition (with vs. without pending goal) served as predictor, time on task-relevant information and on task-irrelevant information served as mediators, respectively, and problem-solving performance was the dependent variable. In both mediation analyses the mediators did not allow explaining differences between conditions in problem-solving performance, that is, there were no significant indirect effects (with time on task-relevant information as mediator: $z = 1.38$, $p = 0.17$; with time on task-irrelevant information as mediator: $z = -1.24$, $p = 0.22$). Thus, even though differences in information processing behavior accompanied the effects of a pending goal on problem-solving performance, the prior was unsuited to explain the latter.

The finding that changes in performance occurred independently of processing task-irrelevant information was corroborated by additional exploratory analyses that were conducted only with students, who had never clicked on the task-irrelevant information ($N = 46$). If performance differences among conditions were caused by processing task-irrelevant information, then we should be unable to confirm our hypotheses for these students. However, rerunning the regression analyses for problem-solving performance and for time on relevant information with only these students revealed the same pattern of results as when analyzing the data of all students. That is, also those students who had never exerted any overt distraction behavior showed reduced performance (overall regression model: $R^2 = 0.20$, $F_{(3, 42)} = 3.56$, MSE $= 360.09$, $p = 0.02$; focal contrast: $\beta = 0.44$, $p = 0.003$) and limited processing of task-relevant information (overall regression model: $R^2 = 0.18$, $F_{(3, 42)} = 2.80$, MSE $= 0.24$, $p = 0.051$; focal contrast: $\beta = 0.38$, $p = 0.009$) when a pending goal was present and they had to solve easy problems. All residual contrasts were non-significant (all $ps > 0.30$).

Discussion

The results from Experiment 2 corroborate our hypotheses to a large extent. In line with Hypothesis 1, a pending goal related to interesting, task-irrelevant information reduced problem-solving performance for students working on easy problems, but not for those working on more difficult ones. Thus, the results confirm predictions derived from volitional action control theories suggesting that a difficult task helps to protect the primary goal from interference caused by a pending goal (e.g., Heise et al., 1994a,b). Moreover, confirming Hypothesis 2, this was accompanied with changes in students' information processing behavior in that students working on easy problems in the pending goal condition processed task-relevant information for a shorter time and task-irrelevant information for a longer time compared with students in the remaining conditions. At first sight these results seem to align with the assumption of Harp and Mayer (1998) as well as Lehman et al. (2007) that the withdrawal of attention away from the relevant toward the irrelevant information is a cause for negative performance effects found in the context of seductive details research. However, in contrast to Hypothesis 3, in the present study these changes in information processing behavior were not causally related to performance; rather, they appeared to be a mere by-product of it. Moreover, even students who did not show any overt distraction behavior were negatively impacted by the presence of a pending goal when working on easy problems. Possible alternative explanations will be discussed in the following section.

GENERAL DISCUSSION

Our experiments were designed to explore the effects of goal competition on task performance and information processing in hypermedia-based learning and problem solving. In line with theories of volitional action control we were able to demonstrate impairments in problem-solving performance when task-irrelevant information was embedded within a hypermedia environment that was related to an explicit pending goal that users were instructed to pursue later. As had been expected in Hypothesis 1, these performance impairments were observable only for students working on easy problems, but not for those working on more difficult problems, thereby confirming prior findings by Heise et al. (1994b, 1997) using a more complex setting. Importantly, performance impairments were not triggered by the mere availability of interesting task-irrelevant information as could be demonstrated in Experiment 1 and as has been furthermore shown by Heise et al. (1994b). Thus, it seems that at least in an experimental laboratory context transient browsing goals are not sufficiently strong to interfere with a learning and problem-solving task that students have been instructed to work on, which is line with findings by Barab et al. (1996). This also corresponds with findings from Harp and Mayer (1998); Harp and Mayer (Experiment 2), who found that introducing learning objectives to support the main (learning) goal led to a significant reduction of the seductive details effect. Goals appear to be useful to constrain users' information search so that users are prevented from getting distracted by task-irrelevant information—at least as long as this information is not related to a pending goal of the user.

Experiment 2 also provided evidence in favor of Hypothesis 2 in that the presence of a pending goal led to more time being spent on the processing of the task-irrelevant information as well as to less time being spent on the processing of the task-relevant information—at least when working on easy problems. There were no comparable effects in Experiment 1. At first sight the changes in information processing behavior appear to be a likely cause of the performance impairments found in Experiment 1 (cf. Harp and Mayer, 1998; Lehman et al., 2007). That is, if students reallocate cognitive resources toward processing task-irrelevant information at the expense of task-relevant information, this is likely to yield worse performance in the problem-solving task (cf. Naumann et al., 2007). However, there was no evidence in our data to confirm this plausible assumption that was addressed in Hypothesis 3. The time spent processing relevant information proved to be no significant mediator for the negative effect of a pending goal on problem-solving performance. Likewise, overt distraction behavior in terms of processing task-irrelevant information did not explain performance impairments. First, it did not mediate the negative effect of a pending goal on problem-solving performance. Second, performance impairments were also observable for students not showing any overt distraction behavior. Moreover, the latter students were in the majority. Third, comparing the conditions from Experiments 1 and 2 that had available interesting, task-irrelevant information (Experiment 1: transient goal conditions; Experiment 1: pending goal conditions) shows that even though in both experiments at least some students processed the interesting information, performance impairments were only observable in Experiment 2. Thus, overt changes in information processing behavior are an unlikely cause of the negative impact of pending goals on task performance. Accordingly, difficult tasks appear to help keep task goals on track in the sense that students are able to maintain a reasonable level of performance even when on a behavioral level they show over distraction behavior.

The hypothesis that overt changes in information processing behavior cause performance impairments had been derived from research on the seductive details effects, where overt distraction behavior (at the expense of processing task-relevant information) is discussed as one possible explanation for why seductive details hamper learning (Harp and Mayer, 1998; Lehman et al., 2007; Rey, 2012). Importantly, even though Lehman et al. (2007) found result patterns that seem to be in line with the idea that changes in overt information processing behavior cause performance impairments, the causal link between these two aspects has not been tested.

The question arises what then causes performance impairments, if not overt distraction behavior. In the literature on the seductive details effect, diversion, disruption, and depletion are discussed as alternative explanations (Harp and Mayer, 1998; Rey, 2012). In our case, it seems unlikely that the interesting information triggered inappropriate schemas for encoding the task-relevant information (diversion) or that its processing interrupts the construction of a coherent mental representation of the relevant information (disruption). In both cases, one would have expected negative effects on problem-solving performance whenever the task-irrelevant information was processed, which was not the case in the reported experiments. The explanation that appears to best match our data is based on a cognitive-resources account (depletion).

According to the depletion explanation, performance impairments arise if task-irrelevant information demands cognitive resources, which are then no longer available for the main task. Theories of volitional action control suggest that it is not the interesting information *per se* that causes negative effects, but the fact that it is related to a pending goal, which is well in line with the present findings. Pending goals reside in memory with a heightened state of activation (Goschke and Kuhl, 1993; Marsh et al., 1999); thus, they withdraw (attentional) resources from the main task (cf. Li et al., 2000). Also deliberating on whether to follow the current or the pending goal as well as suppressing action tendencies to follow the pending goal is likely to claim resources (cf. ego depletion effect, Baumeister et al., 2000). Similarly, Wegner et al. (1987) have suggested that suppressing a thought (e.g., related to a pending goal) may require cognitive resources and be time-consuming. Most importantly, suppressed thoughts may easily return to consciousness when triggers appear in the environment. In our case, hyperlinks providing access to information that was relevant for the pending goal may thus have activated thoughts regarding the pending goal whenever they were encountered and these thoughts interfered with working on the main task. Combining these different strands of research thus allows specifying the depletion explanation: Task-irrelevant information leads to performance impairments if it is linked to a pending goal, in which case there will be a goal conflict in memory, where the current goal and the pending goal compete for limited cognitive resources. Importantly, this requires cognitive resources without necessarily leading to observable engagement with the pending goal, explaining why even students, who do not show overt distraction behavior, suffer from performance impairments.

Such an account would also fit nicely with findings from Sanchez and Wiley (2006), who found a seductive details effect only for students performing low in a working memory task that measured their ability to control attention and to stay focused on a specific goal (Kane et al., 2001). These students should be especially vulnerable to forming transient browsing goals even in the presence of an instructed primary goal and should easily suffer from goal conflicts, explaining why they showed a strong seductive details effect. Moreover, the idea that goal conflicts demand cognitive resources is well in line with hypermedia research suggesting that decisions on whether to retrieve a specific information, which may either be related to the current or the pending goal (i.e., navigational decisions), are one potential source of cognitive overload (Niederhauser et al., 2000). Cognitive overload is seen as one reason for why learning with hypermedia is often not more or even less effective than linear, system-controlled instruction despite its envisioned advantages (Scheiter and Gerjets, 2007; Scheiter, 2014). These problems should become even more evident when considering that many students have difficulties in deciding whether or not a piece of information is relevant to the task at hand once the information space becomes larger and potentially more ambiguous (e.g., in the Internet, Braasch et al., 2009; Goldman et al., 2012).

Even though the results reported in this paper are well in line with previous research, the results require further replication since the present studies were based on relatively small sample sizes. Moreover, because students were allowed to decide whether or not to retrieve the task-irrelevant information, there was huge variability regarding this aspect. Thus, any of the quantitative analyses regarding differences among conditions in students' overt distraction behavior need to be handled with care since only a minority of students actually showed distraction behavior. Importantly, in the present case even though this makes any statistical claims difficult it allowed us to derive important insights, namely, that overt distraction behavior is an unlikely cause of performance impairments.

There are various avenues for future research. First, in the present paper no impact of transient search goals could be observed, which could be due to the experimental situation. Distraction effects due to the activation of personal interests are probably restricted to more natural situations (e.g., browsing the Internet) or to situations where the task-irrelevant information cannot be avoided (cf. seductive details research). Thus, it should be investigated whether transient search goals emerge in more natural Internet browsing scenarios and if so, whether their effects are moderated by the difficulty of the search task, as would be predicted by theories of volitional action control. Second, future research should aim at finding process indicators for the depletion account earlier. For instance, eye tracking could be used to study whether students deliberate for a longer time whether or not to click a link leading to task-irrelevant information when working on easy tasks in the presence of a competing goal. Deliberation should be evident when students attend for a longer time to the respective hyperlinks and move their eyes more frequently between task-relevant and task-irrelevant links (cf. Gerjets et al., 2011, for an application of the eye-tracking method when studying information search). Third, studying the role of individual differences in the paradigm used in the studies reported in this paper could be one way of finding further evidence for the depletion explanation. If goal conflicts are dependent on a person's resources to control their attention, then these resources should moderate the effects of pending goals (cf. Sanchez and Wiley, 2006). This might also imply that effects are different for younger children, whose ability to control attention is still under development or for people with attention control deficits such as children with Attention Deficit and Hyperactivity disorders (cf. Gerjets et al., 2002). Similarly, a person's action orientation, that is, a person's propensity to act and to pursue goals (cf. Kuhl, 1984), should influence how well students are able to accomplish a current task in the face of goal competition (Corno and Kanfer, 1993). Finally, it is important to note that in the present studies task difficulty was manipulated experimentally as a between-subjects variable by choosing different tasks. However, task difficulty will also vary depending on a student's prior knowledge. Thus, it would be interesting to study how students with varying levels of prior knowledge would respond to the presence of a pending goal. On the one hand, one could argue that students with higher compared with lower levels of prior knowledge should be more prone to distraction, since for the prior a given problem is easier than for the latter. On the other hand, once students have prior knowledge available, they can activate more task-relevant concepts in memory, which may possible make them less susceptible to influences of a conflicting goal.

Importantly, the present research has been carried out under the assumption that getting distracted is something negative, because it endangers the accomplishment of a specific educational goal (e.g., finding solutions to clearly defined test problems, acquisition of cognitive skills, memorization of facts). However, providing vast amounts of information may nevertheless be useful for incidental learning. These positive effects of providing a wide range of heterogeneous information for exploratory learning are sometimes described as "serendipity effects" (Kuhlen, 1991). Future studies that use a learning environment with vast amounts of information in combination with varying learning goals may shed light on these possible positive effects of providing potentially distracting information.

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REFERENCES

Abelson, R. P., and Prentice, D. A. (1997). Contrast tests of interaction hypothesis. *Psychol. Methods* 2, 315–328. doi: 10.1037/1082-989X.2.4.315

Altmann, E. M., and Trafton, J. G. (2002). Memory for goals: an activation-based model. *Cogn. Sci.* 26, 39–83. doi: 10.1207/s15516709cog2601_2

Barab, S. A., Bowdish, B. E., Young, M. F., and Owen, S. V. (1996). Understanding kiosk navigation: Using log files to capture hypermedia searches. *Instruct. Sci.* 24, 377–395. doi: 10.1007/BF00118114

Baumeister, R. F., Muraven, M., and Tice, D. M. (2000). Ego depletion: a resource model of volition, self- regulation, and controlled processing. *Soc. Cogn.* 18, 130–150. doi: 10.1521/soco.2000.18.2.130

Braasch, J. L. G., Lawless, K. A., Goldman, S. R., Manning, F. H., Gomez, K. W., and MacLeod, S. M. (2009). Evaluating search results: an empirical analysis of middle school students' use of source attributes to select useful sources. *J. Educ. Comp. Res.* 41, 63–82. doi: 10.2190/EC.41.1.c

Carmel, E., Crawford, S., and Chen, H. (1992). Browsing in hypertext: a cognitive study. *IEEE Trans. Syst. Man Cybern.* 22, 865–884. doi: 10.1109/21.179829

Conklin, J. (1987). Hypertext: an introduction and survey. *IEEE Comp.* 20, 17–41. doi: 10.1109/MC.1987.1663693

Corno, L. (1993). The best-laid plans: modern conceptions of volition and educational research. *Educ. Res.* 22, 14–22.

Corno, L., and Kanfer, R. (1993). The role of volition in learning and performance. *Rev. Res. Educ.* 19, 301–341.

Czerwinski, M., Cutrell, E., and Horvitz, E. (2000a). "Instant messaging and interruption: influence of task type on performance," in *Interfacing Reality in the New Millennium - Proceedings of OZCHI '2000*, eds C. Paris, N. Ozkan, S. Howard, and S. Lu (Sydney, NSW: Computer-Human Interaction Special Interest Group of the Ergonomics Society of Australia), 356–361.

Czerwinski, M., Cutrell, E., and Horvitz, E. (2000b). "Instant messaging: effects of relevance and timing," in *People and Computer XIV - Usability or Else! Proceedings of HCI 2000*, eds S. Turner and P. Turner (New York, NY: Springer), 71–76.

Dillon, A., and Jobst, J. (2005). "Multimedia learning with hypermedia," in *The Cambridge Handbook of Multimedia Learning*, ed R. E. Mayer (New York, NY: Cambridge University Press), 569–588. doi: 10.1017/CBO9780511816819.035

Gerjets, P., Graw, T., Heise, E., Westermann, R., and Rothenberger, A. (2002). Handlungskontrolldefizite und störungsspezifische Zielintentionen bei der Hyperkinetischen Störung II: Empirische Befunde [Action control deficits and disorder-specific goal intentions for hyperkinetic disorders II: empirical findings]. *Z. Klinische Psychol. Psychother.* 31, 99–109. doi: 10.1026//1616-3443.31.2.99

Gerjets, P., Kammerer, Y., and Werner, B. (2011). Measuring spontaneous and instructed evaluation processes during web search: Integrating concurrent thinking-aloud protocols and eye-tracking data. *Learn. Instruct.* 21, 220–231. doi: 10.1016/j.learninstruc.2010.02.005

Goetz, E. T., and Sadoski, M. (1995). Commentary: the perils of seduction: distracting details or incomprehensible abstractions. *Read. Res. Q.* 30, 500–511. doi: 10.2307/747628

Goldman, S. R., Braasch, J. L. G., Wiley, J., and Graesser, A. C. (2012). Comprehending and learning from internet sources: processing patterns of better and poorer learners. *Read. Res. Q.* 47, 356–381. doi: 10.1002/RRQ.027

Gollwitzer, P. M. (1990). "Action phases and mind-sets," in *The Handbook of Motivation and Cognition: Foundations of Social Behavior*, Vol. 2, eds E. T. Higgins, and R. M. Sorrentino (New York, NY: Guilford Press), 53–92.

Goschke, T. (2003). "Voluntary action and cognitive control from a cognitive neuroscience perspective," in *Voluntary Action – Brains, Mind, and Sociality*, eds S. Maasen, W. Prinz, and G. Roth (Oxford: Oxford University Press), 49–85.

Goschke, T., and Kuhl, J. (1993). Representation of intentions: persisting activation in memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 19, 1211–1226. doi: 10.1037/0278-7393.19.5.1211

Harp, S. F., and Mayer, R. E. (1998). How seductive details do their damage: a theory of cognitive interest in science learning. *J. Educ. Psychol.* 90, 414–434. doi: 10.1037/0022-0663.90.3.414

Heise, E., Gerjets, P., and Westermann, R. (1994a). "Idealized action phases: a concise Rubicon-theory," in *Structuralism, Idealization and Approximation*, ed M. Kuokkanen (Amsterdam: Rodopi), 141–158.

Heise, E., Gerjets, P., and Westermann, R. (1994b). Zur Effizienzbeeinträchtigung durch Konkurrenzintentionen bei unterschiedlich schwierigen Tätigkeiten [Efficiency impairments due to competing goal intentions in tasks of varying difficulty]. *Z. Exp. Angewandte Psychol.* 41, 549–565.

Heise, E., Gerjets, P., and Westermann, R. (1997). The influence of a waiting intention on action performance: efficiency impairment and volitional protection in tasks of varying difficulty. *Acta Psychol.* 97, 167–182. doi: 10.1016/S0001-6918(97)00027-9

Hirashima, T., Hachiya, K., Kashihara, A., and Toyoda, J. (1997). Information filtering using user's context on browsing in hypertext. *User Model. User-adapt. Interact.* 7, 239–256. doi: 10.1023/A:1008239629258

Kane, M. J., Bleckley, M. K., Conway, A. R. A., and Engle, R. W. (2001). A controlled-attention view of working-memory capacity. *J. Exp. Psychol. Gen.* 130, 169–183. doi: 10.1037/0096-3445.130.2.169

Kuhl, J. (1984). "Volitional aspects of achievement motivation and learned helplessness: toward a comprehensive theory of action control," in *Progress in Experimental Personality Research*, Vol. 13, eds B. A. Maher and W. B. Maher (New York, NY: Academic Press), 100–171.

Kuhlen, R. (1991). *Hypertext - Ein nicht-lineares Medium zwischen Buch und Wissensbank [Hypertext - A Non-Linear Medium Between Book and Knowledge Base]*. Berlin: Springer.

Lehman, S., Schraw, G., McCrudden, M., and Hartley, K. (2007). Processing and recall of seductive details in scientific text. *Contemp. Educ. Psychol.* 32, 569–587. doi: 10.1016/j.cedpsych.2006.07.002

Lenhart, A., Rainie, L., and Lewis, O. (2001). *Teenage Life Online: The Rise of the Instant-Message Generation and the Internet's Impact on Friendships and Family Relationships.* Washington, DC: Pew Internet and American Life Project. Available online at: http://www.pewinternet.org/~/media//Files/Reports/2001/PIP_Teens_Report.pdf.pdf (Accessed November 28, 2013).

Li, K. Z. H., Lindenberger, U., Rünger, D., and Frensch, P. A. (2000). The role of inhibition in the regulation of sequential action. *Psychol. Sci.* 11, 347–351. doi: 10.1111/1467-9280.00268

Marsh, R. L., Hicks, J. L., and Bryan, E. S. (1999). The activation of unrelated and canceled intentions. *Mem. Cogn.* 27, 320–327. doi: 10.3758/BF03211415

Naumann, J., Richter, T., Flender, J., Christman, U., and Groeben, N. (2007). Signaling in expository hypertexts compensates for deficits in reading skill. *J. Educ. Psychol.* 90, 791–807. doi: 10.1037/0022-0663.99.4.791

Niedenthal, P. M., Brauer, M., Robin, L., and Innes-Ker, Å. H. (2002). Adult attachment and the perception of facial expression of emotion. *J. Pers. Soc. Psychol.* 82, 419–433. doi: 10.1037/0022-3514.82.3.419

Niederhauser, D. S., Reynolds, R. E., Salmen, D. J., and Skolmoski, P. (2000). The influence of cognitive load on learning from hypertext. *J. Educ. Comput. Res.* 23, 237–255. doi: 10.2190/81BG-RPDJ-9FA0-Q7PA

Preacher, K. J., and Hayes, A. F. (2008). Asymptotic and resampling strategies for assessing and comparing indirect effects in multiple mediator models. *Behav. Res. Methods* 40, 879–891. doi: 10.3758/BRM.40.3.879

Rey, G. D. (2012). A review of research and a meta-analysis of the seductive detail effect. *Educ. Res. Rev*. 7, 216–237. doi: 10.1016/j.edurev.2012.05.003

Ross, B. H., and Kilbane, C. (1997). Effects of principle explanation and superficial similarity on analogical mapping in problem solving. *J. Exp. Psychol. Learn. Mem. Cogn.* 23, 427–440. doi: 10.1037/0278-7393.23.2.427

Sanchez, C. A., and Wiley, J. (2006). An examination of the seductive details effect in terms of working memory capacity. *Mem. Cognit*. 34, 344–355. doi: 10.3758/BF03193412

Scheiter, K. (2014). "The learner control principle," in *The Cambridge Handbook of Multimedia Learning, 2nd Edn.* ed R. E. Mayer (New York, NY: Cambridge University Press), 487–512.

Scheiter, K., and Gerjets, P. (2007). Learner control in hypermedia environments. *Educ. Psychol. Rev.* 19, 285–307. doi: 10.1007/s10648-007-9046-3

Wegner, D. M., Schneider, D. J., Carter, S., and White, T. (1987). Paradoxical effects of thought suppression. *J. Pers. Soc. Psychol.* 53, 5–13. doi: 10.1037/0022-3514.53.1.5

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Distractibility during retrieval of long-term memory: domain-general interference, neural networks and increased susceptibility in normal aging

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The mere presence of irrelevant external stimuli results in interference with the fidelity of details retrieved from long-term memory (LTM). Recent studies suggest that distractibility during LTM retrieval occurs when the focus of resource-limited, top-down mechanisms that guide the selection of relevant mnemonic details is disrupted by representations of external distractors. We review findings from four studies that reveal distractibility during episodic retrieval. The approach cued participants to recall previously studied visual details when their eyes were closed, or were open and irrelevant visual information was present. The results showed a negative impact of the distractors on the fidelity of details retrieved from LTM. An fMRI experiment using the same paradigm replicated the behavioral results and found that diminished episodic memory was associated with the disruption of functional connectivity in whole-brain networks. Specifically, network connectivity supported recollection of details based on visual imagery when eyes were closed, but connectivity declined in the presence of visual distractors. Another experiment using auditory distractors found equivalent effects for auditory and visual distraction during cued recall, suggesting that the negative impact of distractibility is a domain-general phenomenon in LTM. Comparisons between older and younger adults revealed an aging-related increase in the negative impact of distractibility on retrieval of LTM. Finally, a new study that compared categorization abilities between younger and older adults suggests a cause underlying age-related decline of visual details in LTM. The sum of our findings suggests that cognitive control resources, although limited, have the capability to resolve interference from distractors during tasks of moderate effort, but these resources are overwhelmed when additional processes associated with episodic retrieval, or categorization of complex prototypes, are required.

Keywords: distraction, long-term memory, categorization, top-down control, episodic memory

INTRODUCTION

A growing body of research shows that the presence of irrelevant information, which is a common factor in our real-world environment, diminishes performance in visual working memory (WM) (Rainer et al., 1998; Lavie, 2005; Zanto and Gazzaley, 2009; Clapp et al., 2010) and in the retrieval of details from long-term memory (LTM) (Wais et al., 2010, 2012a; Wais and Gazzaley, 2011). The ability to remain focused on relevant visual stimuli in the presence of distractors is thought to depend on selective visual attention (Desimone, 1998; Lavie and de Fockert, 2005). Neuroimaging evidence suggests that perceptual processing of visual distraction interferes with connectivity of functional networks that guide visual attention to achieve memory goals. Moreover, the effect of visual distraction on performance increases with normal aging in the domains of WM (Gazzaley et al., 2005a; Berry et al., 2009) and LTM (Wais et al., 2012b).

We review here the implications of recent findings from behavioral and neuroimaging results that the presence of visual distraction negatively impacts the fidelity of LTM retrieval. Additionally, we discuss results that suggest the negative impact of distractibility on details retrieved from LTM is a domain-general phenomenon—a finding that suggests a direct relationship between the increased susceptibility to visual distraction in normal aging and impairment in categorization abilities.

DISTRACTION REDUCES FIDELITY OF LONG-TERM MEMORY RETRIEVAL

Previous behavioral studies have shown that engagement in a secondary cognitive task during LTM retrieval (i.e., divided attention) interferes with free recall (Fernandes and Moscovitch, 2000) and source memory (Troyer et al., 1999). Our motivation was to investigate the impact of distraction by entirely irrelevant visual information on a participant's singular goal of retrieving episodic details from LTM. Because attentional resources are limited (Pashler and Shiu, 1999), the top-down effort required to retrieve details relevant for memory goals may suffer when incidental attention to the irrelevant visual information diverts resources away from LTM goals. Although this diversion would be clearly driven by bottom-up processes, because there are no top-down goals to attend to the visual stimuli, excessive demands on brain regions and networks in common across these processes may result in substantially diminished fidelity of LTM.

Our experimental approach used in several studies was to cue participants to recall previously studied objects during blocks when their eyes were closed, or were open and irrelevant visual information was present. We hypothesized that because visual imagery in support of episodic retrieval utilizes the same limited-capacity lateral occipital cortex (LOC) buffers that are involved in processing external visual stimuli (De Fockert et al., 2001; Lavie, 2005), as well as overlapping cognitive control networks (Blumenfeld and Ranganath, 2006), visual stimulation during a retrieval effort would disrupt the access to or fidelity of details about a prior experience stored in LTM. This may be the driving force behind common acts of looking away or closing one's eyes when engaged in effortful recollection (Glenberg et al., 1998), reflexive efforts that may serve to block interference between irrelevant external information and recalling details from memory.

RESULTS FOR VISUAL DISTRACTION

In a behavioral study, participants studied images of common objects during two incidental encoding tasks, and, after a 1-h retention interval, responded old or new to auditory cues for target and lure objects (Wais et al., 2010). During encoding, each object image displayed one to four copies of a common object from a three-dimensional perspective. During test blocks, an auditory cue described an object encoded in the previous session, or a novel (i.e., lure) object, in singular form. Participants were instructed to recall the count for the object described by the cue and give their answer by responding 1, 2, 3, 4, or "new." Correct responses for the object count indicated retrieval of goal-relevant episodic information. Test blocks presented auditory cues for targets in three different conditions: when visual stimulation was nil (eyes closed: SHUT), when bottom-up processing was minimal (looking at a gray screen: GRAY), and when neutral, visual environmental stimuli were presented (Visual Distraction, or VD) (**Figure 1**). The visual stimuli appeared simultaneously with the presentation of the auditory cues, and participants were instructed to fix their gaze at the center of the computer screen during stimulus presentation in GRAY and VD trials.

Overall memory performance for each of the test conditions was indexed using an estimation of d′ for each participant (mean overall $d' = 2.10 \pm 0.09$), a measure that contrasts the hit rate for targets with the false alarm rate for lures (Macmillan and Creelman, 2005). A comparison across test conditions showed a main effect of condition, such that d′ was greater for SHUT than both GRAY and VD (**Table 1**; Visual Distractors, younger adults). Comparison across conditions of the responses for the targets revealed a main effect of condition for the proportion given the correct count, and pair-wise tests showed that episodic retrieval during VD was significantly reduced compared to both SHUT and GRAY (**Figure 2A**).

The results revealed that irrelevant visual stimuli presented during a memory test diminished the fidelity of details retrieved from LTM. This finding suggests that there is a critical role for cognitive control processes in minimizing the disruptive influence of irrelevant external information during episodic retrieval. Notably, the failure to inhibit the processing of distractions had also been shown in previous research to diminish accuracy in perception and visual WM (Lavie et al., 2004; Gazzaley et al., 2005b, 2008; Zanto and Gazzaley, 2009; Clapp et al., 2010).

Recent studies have distinguished between the impact of interference from distraction (entirely irrelevant information) and interruption (relevant information for a secondary task) on WM, and revealed that distinct neural mechanisms underlie these two types of interference (Clapp et al., 2010), as well as the presence of differential effects in aging (Clapp and Gazzaley, 2012). Our first study specifically explored the influence of distraction-related interference on LTM retrieval, as the visual stimuli in the VD condition were entirely irrelevant (i.e., participants were explicitly instructed to direct their undivided attention to the goal of responding to the memory test). Our findings of a decrement in episodic retrieval in the setting of distraction parallel the documented impact by interruption (dual-tasking) on LTM (Jacoby, 1991; Troyer et al., 1999; Fernandes and Moscovitch, 2000; Fernandes et al., 2006), but given the data from WM experiments, it is reasonable to hypothesize that distraction and interruption effects on LTM likely involve distinct neural mechanisms.

Our results also raise the possibility that two, non-mutually exclusive, neural mechanisms may underlie the impact of distraction on episodic retrieval. First, bottom-up, visual processing of external information may result in a decrease in the fidelity of internal representations of memoranda generated via visual imagery during the retrieval period, because both types of representations rely on overlapping regions of visual cortices. For example, the fidelity of details retrieved in imagery in response to memory task goals (i.e., the precise count of pumpkins on the studied image) could be diminished due to interference from processing concurrent, although irrelevant, visual information. In this example, recollection of details would be disrupted, yet a general assessment of recognition accuracy (i.e., are pumpkins old or new?) would not reveal an impact of distraction. Second, because attentional resources are limited (Pashler and Shiu, 1999), top-down effort required to retrieve memories when cued may suffer when incidental attention to the irrelevant visual information diverts resources away from LTM goals, resulting in diminished fidelity of episodic details. Interestingly, studies that examined effects of distraction in circumstances like eyewitness testimony have reported findings convergent with our results from trial-wise tests of cued recall. The findings showed recall for visual details was superior in eyes closed, relative to eyes open, conditions (Perfect et al., 2011; Vredeveldt et al., 2011) and support the interpretation that eye closure removes the cognitive load associated with monitoring the external environment.

RESULTS FOR AUDITORY DISTRACTION

Another behavioral study utilized an experimental paradigm that paralleled the previous study, but substituted auditory distractors in place of visual distractors (Wais and Gazzaley, 2011). Because bottom-up processing of auditory stimuli and internal visual representations of items in memory are thought to be supported by discrete sensory cortices, our rationale for this next study was that if auditory distraction effects were present, then the convergence of these results with those from the prior study would

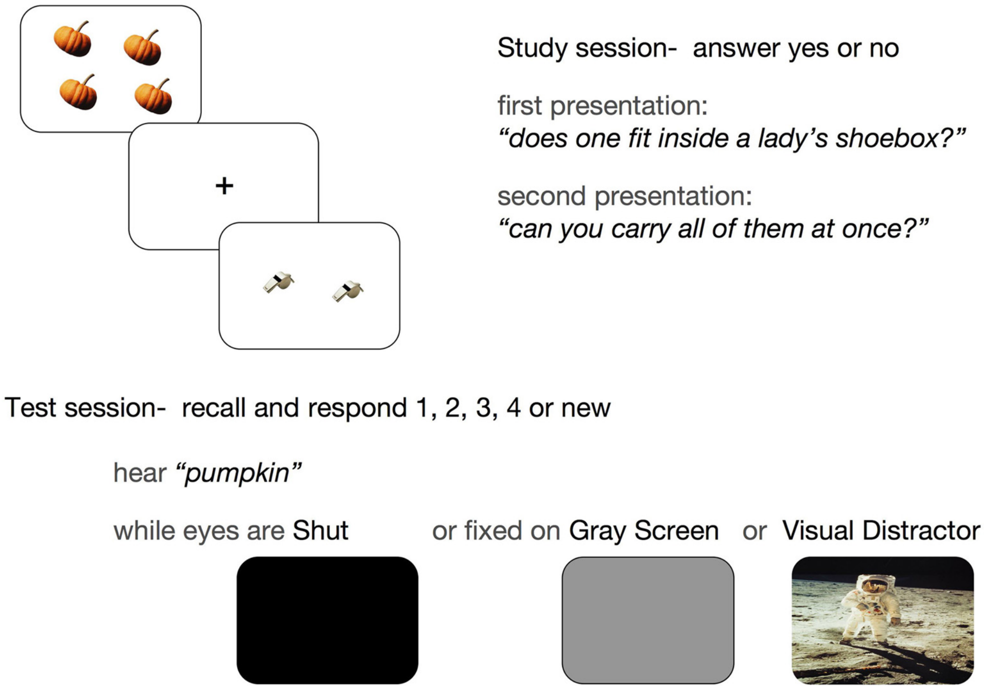

FIGURE 1 | Experimental paradigm. A schematic of the procedure shows the study session, when participants answered two incidental questions about each of 168 images (3 s per presentation), and the test session, when auditory cues described 168 targets and 36 lures in singular form (2.5 s per presentation, 10.0 s inter-trial interval). Participants' recall was tested during in three conditions: SHUT, GRAY, and Visual Distractor (VD) (Wais et al., 2010).

Table 1 | Behavioral results for groups of younger and older adults.

	Visual distractors			Auditory distractors		
	SHUT	**GRAY**	**VD**	**Silence**	**WN**	**AD**
YOUNGER ADULTS						
Proportion correct	0.59 (0.03)	0.57 (0.03)	0.53 (0.02)	0.61 (0.03)	0.60 (0.02)	0.56 (0.03)
Recognition d′	2.46 (0.13)	2.11 (0.14)	1.97 (0.10)	2.07 (0.12)	2.25 (0.10)	2.23 (0.12)
OLDER ADULTS						
Proportion correct	0.48 (0.02)	0.46 (0.03)	0.40 (0.02)			
Recognition d′	1.56 (0.14)	1.63 (0.13)	1.70 (0.12)			

Summaries for each of three experiments show group means for the proportion of targets given correct responses and for recognition d′ (i.e., comparison of hit rate to false alarm rate) in each condition (standard error of the mean). Different groups of younger adults participated in experiments with either visual or auditory distractors: SHUT and Silence presented no external information during memory test trials; GRAY and white noise (WN) presented control stimuli; and visual distractors (VD) and auditory distractors (AD) presented external information irrelevant for the goal of episodic retrieval. A group of older adults completed a standardized neuropsychological battery, and scored within 2.0 standard deviations of their age-matched normative value, before participating in a visual distraction experiment using the same paradigm as the younger adults.

suggest that external interference effects on episodic retrieval occur in a domain general manner. The experimental paradigm utilized written cues to probe recall of visual details of previously studied objects when participants were: (1) in complete silence, (2) exposed to white noise, or (3) exposed to ambient sounds recorded at a busy café. The target stimuli and encoding procedure in the current study with auditory distraction were identical to those in the previous study with visual distraction.

We examined the impact of auditory distraction on retrieval of visual memories, and then compared those results to our findings that revealed the impact of visual distraction on LTM retrieval. Estimates of d′ were used in a comparison of overall performance (mean overall $d' = 2.14 \pm 0.08$, **Table 1**; Auditory Distractors, younger adults), and there was no effect between the control and distraction conditions (i.e., Silence, White Noise, and AD). Comparison of the responses for the targets across conditions revealed a main effect of condition for the proportion given the correct count, such that episodic retrieval was significantly disrupted by auditory distraction (**Figure 2B**). Pair-wise comparisons showed that episodic retrieval during AD was reduced

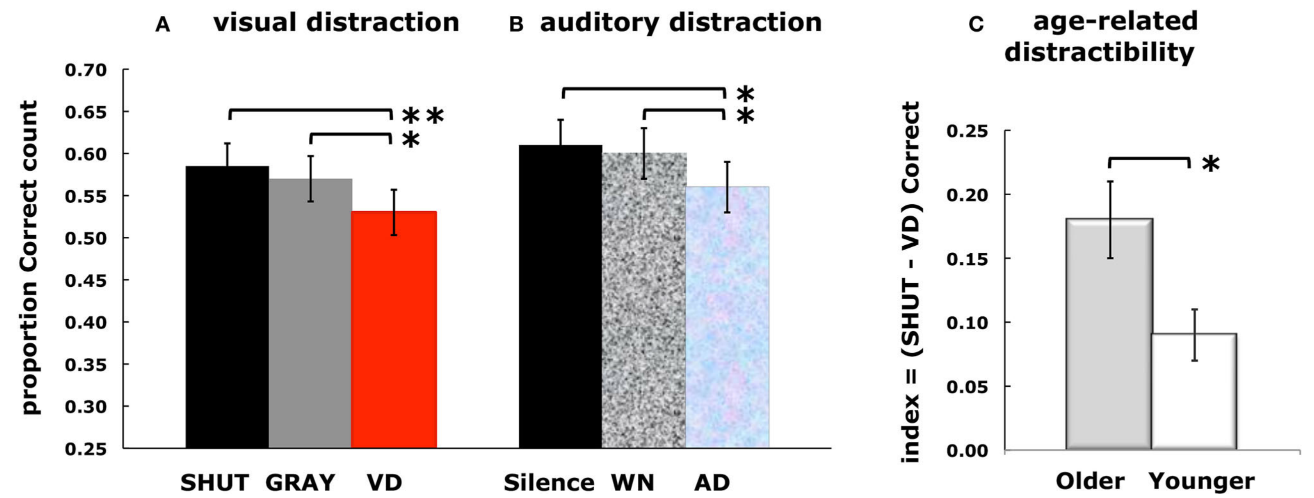

FIGURE 2 | Results from behavioral experiments. Episodic retrieval scores are presented for three studies that used separate groups of participants. Each panel shows the negative influence of external distraction. For visual distractors **(A)**, the mean proportion of targets given responses with the correct count by a group of younger adults is diminished in the visual distraction (VD) condition relative to the SHUT and GRAY conditions. For auditory distractors **(B)**, the results from younger adults show the same pattern of diminished performance in the auditory distraction (AD) condition, relative to the silence and white noise (WN) conditions, as observed for visual distraction. A comparison between groups of younger and older adults **(C)** who completed the visual distraction paradigm revealed that the disruptive influence of distraction diminished the fidelity of episodic retrieval to a greater degree for older adults than younger adults. Error bars represent the standard error of the mean, $^*p < 0.05$, and $^{**}p < 0.001$.

compared to both Silence and White Noise, with no significant difference between Silence and White Noise.

A direct comparison was performed between results of the auditory distractor study with the visual distractor study (Wais et al., 2010). In the auditory distraction experiment, the conditions for no distractor (Silence), control distractor (White Noise), and distractor (AD) were analogous, respectively, to eyes shut (Shut), eyes open with gray screen (Gray), and eyes open with complex natural scenes (VD) in the visual distraction experiment. Conditional correct scores computed the proportion of responses for a correct count given that an item was not forgotten [i.e., p(Correct)/(1-p(Forgotten)] and were used to compare performance with a mixed-design, 2 distractor modality (auditory, visual) × 3 condition (no distractor, control distractor, distractor) ANOVA. The results showed a main effect of condition such that retrieval of relevant visual details during the distractor conditions declined relative to both the no distractor and control distractor conditions. There was no difference in the pair-wise comparison between the no distractor and control distractor conditions. Critically, there was no main effect of distractor modality and no interaction between condition and distractor modality.

The comparison across the experiments revealed that there was no difference in effect between distractor modality: i.e., auditory and visual information irrelevant to the LTM goal induced equivalent interference effects on retrieval of task-relevant, visual details. In our results, the influence of distraction on episodic retrieval of visual details is, therefore, independent of the sensory domain of the distractor. Other studies that examined effects of visual and auditory distraction during eyewitness-like recall have found evidence for modality-specific interference (Vredeveldt et al., 2011) and particular susceptibility for visual distraction (Perfect et al., 2011). Compared to these findings, the domain generality of distractors' disruptive influence in our results may have to do with the high level of attentional demands in our trial-wise, time-constrained tests for retrieval of specific visual details. The disruptive impact on domain general processes could be explained by either top-down or bottom-up interference (which are not mutually exclusive). Specifically, LOC regions supporting visual imagery for the target images might be impacted by bottom-up influences from the multisensory processing of visual or auditory stimuli (Ghazanfar and Schroeder, 2006), or regions of the prefrontal cortex (PFC) that mediate top-down signals to visual pathway regions might be disrupted in a domain independent manner (Ranganath et al., 2004). Because there is no direct overlap in primary sensory regions, it is more likely that the former explanation is the cause of the distraction effect.

IMPACT OF VISUAL DISTRACTION ON EPISODIC RETRIEVAL IN OLDER ADULTS

Cognitive aging takes a toll on both the encoding (Ferguson et al., 1992) and retrieval (Hashtroudi et al., 1990) of information that forms our awareness of prior experiences—memories. Research aimed at characterizing the specific nature of LTM impairment has highlighted age-related deficits in retrieval of episodic information (Li et al., 2004) and suggests that older adults do not retrieve vivid, detailed information about prior episodes as effectively as younger adults (Craik, 2002). To explore the impact of visual distraction on LTM in older adults, we utilized the same experimental paradigm used previously with younger adults (Wais et al., 2010; Wais and Gazzaley, 2011).

In our study of older adults (Wais et al., 2012b), the incidental encoding procedure was the same for all target images (i.e., the study session), which held the detail and quantity of information equivalent for all test stimuli. Therefore, any impairment that existed in the older adults' ability to encode the details of studied stimuli (Chalfonte and Johnson, 1996) would impact each test condition equally (i.e., SHUT, GRAY, and VD). Furthermore, because the incidental encoding procedure and retention interval were the same as used previously with younger adults, the analysis could distinguish between a generalized age-related decline in LTM performance and a differential impact of visual distraction on episodic retrieval in older adults.

Overall recognition performance (mean overall $d' = 1.63 \pm 0.12$) was compared between conditions using estimates of d′ (**Table 1**; Visual Distractors, older adults). A mixed-design ANOVA (younger/older × SHUT/GRAY/VD) for estimates of d′ revealed a main effect of age, no effect of condition, and an interaction of age and condition. The interaction of age and condition on d′ reflected better performance by younger adults when visual distractors were not present: SHUT, young > old; GRAY, younger > older; and no difference between younger and older in VD.

A mixed-design ANOVA (younger/older × SHUT/GRAY/VD) compared conditional correct scores [i.e., for targets, *p*(Correct)/(1-*p*(Forgotten)] and revealed a main effects of age and of condition, as well as an interaction of age and condition. To interrogate this interaction, both within-group and between-group tests were performed. Pair-wise comparisons within the older adult group showed that retrieval of relevant visual details declined significantly in VD relative to SHUT and GRAY, and there was no difference between conditional correct scores for SHUT and GRAY. Between-group comparisons, which directly compared conditions for older and younger adults, revealed an aging-related decline in episodic retrieval in VD, while there were only trends for aging-related declines in SHUT and GRAY. This finding that older adults exhibited diminished detailed LTM in the setting of visual distraction is in contrast to the absence of an age-related change on overall recognition as the impact of distraction, thus establishing the selectivity of distractibility on episodic retrieval.

Further analyses used a distraction index to account for overall differences between age groups in the fidelity of LTM retrieval induced by distraction. For each older and younger participant, a distraction index was calculated for conditional correct scores (i.e., SHUT correct—VD correct). A greater index corresponds to greater disruption by distraction during episodic retrieval, that is to say greater distractibility. An independent samples test of the distraction index, assuming unequal variances, revealed greater distractibility in the older adults than the younger adults (**Figure 2C**). The result of the comparison of distractibility indices provides strong evidence that visual distraction disrupted retrieval of relevant details from LTM to a greater degree in older than younger adults.

Our interpretation of the results that show episodic retrieval in older adults is more susceptible to disruption by irrelevant, external information is that decline in performance was caused by interference on control processes mediating the selection of specific mnemonic details. Several explanations have been proposed for the selective decline in recollection in normal aging, including deficits in retrieving multiple features (Chalfonte and Johnson, 1996), in the vividness and complexity of visual imagery for prior experiences (Henkel et al., 1998), and in the ability to merge associations that form episodes (Naveh-Benjamin et al., 2003). These deficits all reflect diminished accessibility to specific details about prior experiences. A common feature influencing all of these deficits, including the results from the current study, may be an impact of interference on selection processes that support retrieval of detailed memories.

The current findings may reflect a more fragile top-down control network in older adults, even when the older participant's eyes were shut, which explains the trend of weaker episodic memory performance in SHUT compared to younger adults. Top-down control guiding the selection of relevant details during episodic retrieval would then be further compromised by interference from visual distraction, resulting in a larger cumulative impact on memory retrieval processes in older adults when irrelevant, external information was present. Further research using neuroimaging will be required to elucidate the impacted neural networks that generate increased susceptibility to interference in the presence of visual distraction, which in turn underlies the weakened fidelity of LTM in normal aging.

NEURAL MECHANISMS UNDERLYING DISTRACTIBILITY DURING LTM RETRIEVAL

In an fMRI experiment (Wais et al., 2010), we examined the neural networks that support episodic retrieval involving visual imagery and how functional connectivity in those networks is impacted by the presence of irrelevant visual information. The study used the same paradigm and stimuli from the related behavioral experiment and included minor adjustments in stimulus timing to accommodate the fMRI procedure. Evaluation of the neural basis of interference effects using fMRI involved first contrasting univariate data in the SHUT condition associated with trials when the correct count was given (i.e., episodic retrieval) vs. trials when an incorrect count was given. This contrast enabled the identification of brain regions of interest associated with successful episodic retrieval, which were then used as seeds in a functional connectivity analysis to characterize neural networks that supported episodic retrieval in the absence of external distraction. Subsequent contrasts between the SHUT and VD conditions explored the neural basis of interference induced by the presence of irrelevant visual information. We hypothesized that retrieval of the details of the studied images would be impaired when visual distraction was present during the memory test, and that this interference would be mediated via disruption of functional neural networks involving memory regions in the medial temporal lobe (MTL), control regions in the PFC and stimulus-selective regions in the lateral occitpital cortex (LOC).

The performance results for the participants tested in the MRI scanner replicated the previous behavioral study: the fidelity of details retrieved from LTM was diminished in the presence of visual distraction, relative to the eyes shut condition. The first step in the fMRI analysis was to identify regions in a whole-brain contrast where activity increased in association with correct, relative to incorrect, cued recall responses in the condition that was free of influence from external visual stimuli (i.e., SHUT). Three regions revealed increased activity in support of episodic retrieval during SHUT: the left hippocampus, the right hippocampus, and the left LOC (all *p-corrected* < 0.05). Of note, the left LOC region that supported episodic retrieval in SHUT overlapped with the object-selective ROI identified in a separate object localizer block. Activity increased in this LOC region above the fixation baseline despite eyes being closed, and no increases were observed in other LOC regions in association with either SHUT correct or SHUT incorrect responses, relative to the forgotten items or baseline fixation. This pattern of increased activity in a stimulus-selective area of the left LOC could not have been associated with processing external visual stimuli because the participants' eyes were closed during these trials.

To assess the mechanism underlying the impact visual distraction has on episodic retrieval, we first interrogated the two hippocampal ROIs that were identified to subserve correct recall responses in the SHUT condition. This analysis revealed a differential impact by distraction in the VD condition such that the signal in the left hippocampus ROI was reduced in VD correct, relative to SHUT correct. The next step was a whole-brain, beta-series correlation analysis performed to assess functional networks including the hippocamal and LOC regions identified by the univariate analyses in the SHUT condition. Using network maps generated from these two seed regions, a contrast revealing greater functional connectivity in SHUT correct than SHUT incorrect trials identified a cortical network that included regions in the PFC, the insula and the posterior parietal cortex. A conjunction analysis of these network regions that supported episodic retrieval in SHUT revealed a single region in the left ventrolateral PFC [inferior frontal gyrus (IFG), BA45] that exhibited greater functional connectivity in common with the left hippocampus and the left LOC seed during SHUT correct than incorrect (**Figure 3A**). This left VLPFC region has been previously identified in studies utilizing univariate analysis as being a control region associated with selection of contextual information during LTM retrieval (Kahn et al., 2004; Dobbins and Wagner, 2005; Law et al., 2005; Wais et al., 2010; Wais, 2011). Moreover, the left VLPFC has also been identified in studies that mapped reinstatement of cortical encoding activity during later recognition tests (Wheeler and Buckner, 2004; Johnson et al., 2009).

Next, we evaluated the impact on this functional network from visual distraction during episodic retrieval. In comparisons of the left-lateralized hippocampus-VLPFC-LOC network between the SHUT and VD conditions, functional connectivity decreased in association with VD correct, relative to SHUT correct, and, critically, no longer supported episodic retrieval (i.e., functional connectivity was not different between VD correct and VD incorrect). Moreover, a regression analysis revealed that the change in network connectivity between SHUT correct and VD correct was correlated for an index of left VLPFC with left hippocampus connectivity and an index of left VLPFC with left LOC connectivity (**Figure 3B**). The results showed, therefore, that when VLPFC network connectivity decreased with the left LOC, it also decreased with the left hippocampus and that disruption of connectivity in this network was associated with diminished fidelity of episodic retrieval.

PERTURBATION OF LEFT VLPFC

The mutual functional connectivity of the left VLPFC region with an object-selective region involved in visual imagery and a memory region critical for episodic retrieval suggests that the left VLPFC may serve as a source of cognitive control in a functional network necessary for the selection of contextual mnemonic details based on visual imagery. Based on the results from the fMRI study, the causal involvement of the left VLPFC ROI in episodic retrieval was assessed using repetitive transcranial magnetic stimulation (rTMS) to perturb normal function immediately prior to test blocks in the memory test (Wais et al., 2012a). Our approach incorporated two separate controls, such that the effects of actual rTMS perturbation could be compared to sham rTMS, (i.e., perturbation control when the rTMS pulse is not directed at the brain) and the effects of rTMS to the VLPFC could be compared to a cortical region not associated with LTM function or higher order cognition (i.e., vertex control). Thus, each participant engaged in two separate experiments—rTMS and sham rTMS applied at the left VLPFC and, on a different day, rTMS and sham rTMS applied at the vertex (**Figure 4A**).

The causal role of the VLPFC ROI in episodic retrieval was assessed in the SHUT and VD conditions by submitting the proportions of Correct cued-recall responses to a comparison between treatment and retrieval conditions. The results from a repeated-measures ANOVA of Site (VLPFC|vertex) $\times$ rTMS (sham|actual) $\times$ Condition (SHUT|VD) revealed a main effect of Condition and a significant interaction of Site $\times$ Condition. Correct responses decreased during VD, relative to SHUT, and this disruption of episodic retrieval was to a greater degree in the VLPFC experiment than the Vertex experiment (**Figure 4B**). The ANOVA also strongly suggested the interaction of rTMS $\times$ Condition, such that Correct responses were reduced during VD, relative to SHUT, to a greater degree after actual rTMS than sham. Moreover, the difference in Correct responses between conditions can be presented as an index of distractibility on episodic retrieval (i.e., SHUT Correct—VD Correct), and a comparison of this index between Sites revealed that the effect of distraction was exacerbated in the VLPFC experiment. Thus, the comparison of the distractibility index after actual rTMS, relative to that index after sham, further suggests that distraction was exacerbated by active rTMS to the left VLPFC.

SUMMARY OF FINDINGS FROM NEUROIMAGING

The fMRI study revealed for the first time that the fidelity of episodic retrieval declines in the presence of irrelevant external information and that this decline is associated with disrupted hippocampal function. Our interpretation of the fMRI results obtained during the SHUT condition is that the fidelity of episodic retrieval depends upon reinstatement of encoded representations for details relevant to memory goals, or visual imagery. This is consistent with results from previous fMRI studies that have shown reinstatement of activity associated with encoding visual stimuli when recognition was successful (Wheeler and Buckner, 2004; Johnson and Rugg, 2007; Johnson et al., 2009). However, the conclusions from prior research were limited to interpretations about subjective recollection and by the processing of visual memory cues concurrent with reinstatement

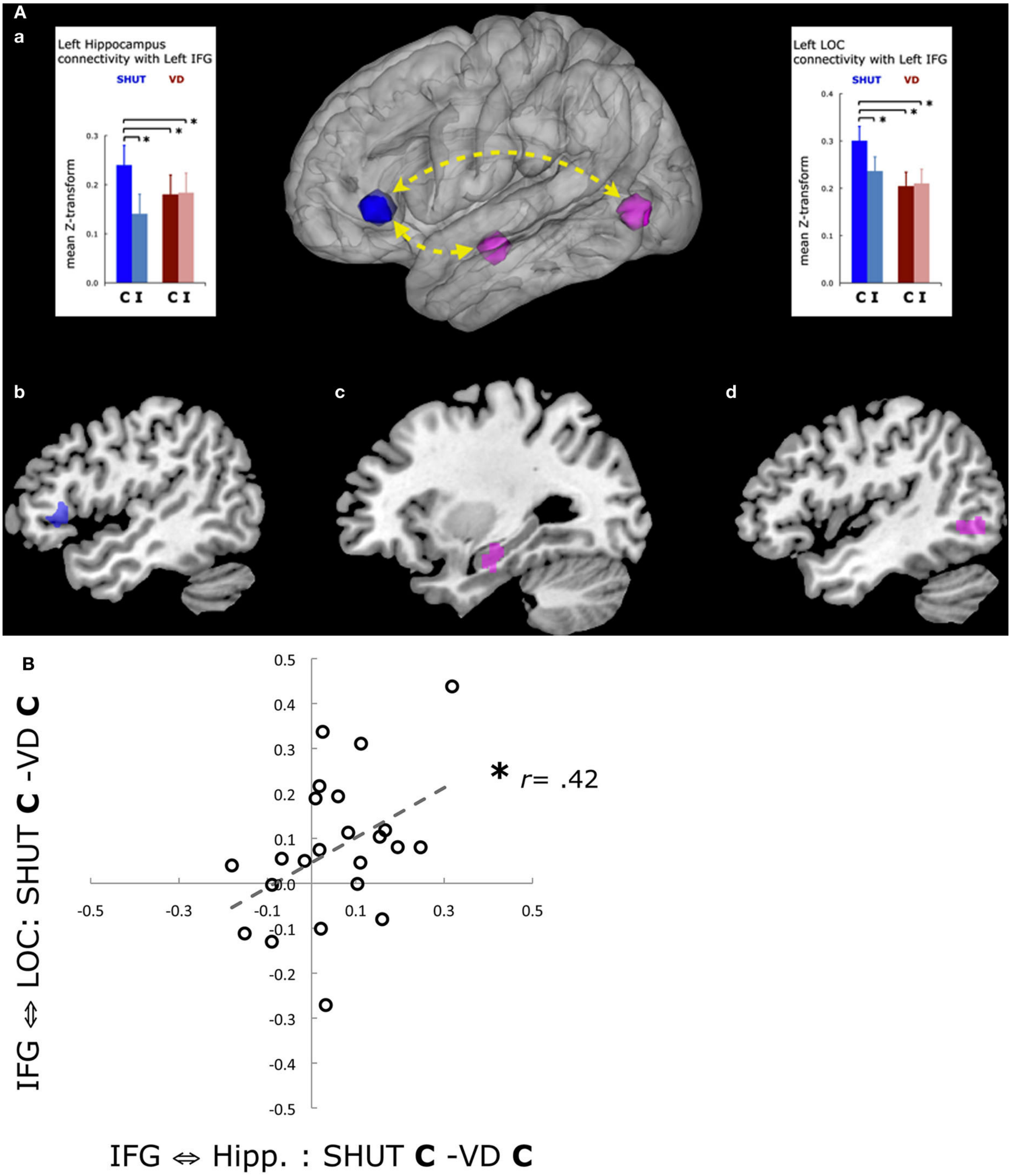

FIGURE 3 | (A) fMRI results associated with visual distraction. The conjunction of functional connectivity with the left IFG was mapped by the whole-brain comparison of beta-series correlations seeded by the left hippocampal ROI identified in the univariate analysis and by the left LOC cluster identified in the independent functional localizer task (Wais et al., 2010). Further comparisons in this memory retrieval network revealed that functional connectivity was disrupted during VD correct, relative to SHUT correct. **(a)** A schematic of the network is shown with functional connectivity between the regions plotted as the mean z-score transformation of the beta-series correlations for each of four categories for responses to the targets. The network regions include: **(b)** the left IFG (blue); **(c)** the left hippocampus (violet); and **(d)** the left LOC (green). Error bars represent the standard error of the mean, and $^*p < 0.05$. **(B)** Disruption of functional connectivity in memory networks is associated with diminished episodic retrieval. A scatter plot shows the values for each participant in a regression analysis of functional connectivity between the left IFG and the left hippocampus ROIs (x-axis, SHUT correct vs. VD correct) and the left IFG and the left LOC ROIs (y-axis, SHUT correct vs. VD correct). The analysis revealed that reduced left IFG connectivity with the left LOC was correlated with reduced connectivity with the left hippocampus (Wais et al., 2010). Trend lines show the slope of significant correlations, and $^*p < 0.05$.

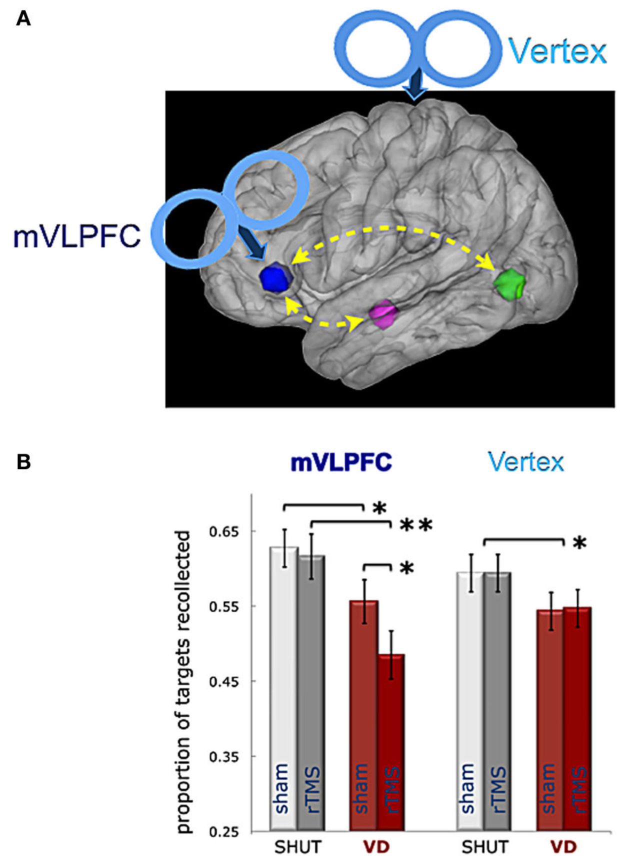

FIGURE 4 | Role of left VLPFC in episodic retrieval during visual distraction. A schematic illustration **(A)** shows the rTMS targets located on a sagittal rendering of the MNI template brain, including the mVLPFC ROI (blue) functionally connected in a recollection network with the left hippocampus (magenta) and lateral occipital cortex (green), as represented in Wais et al. (2012a). **(B)** The mean proportion of targets given the correct count is shown in each experiment by condition (SHUT, VD) after sham or actual rTMS treatment. Results show an interaction of actual rTMS on episodic retrieval during visual distraction after VLPFC treatment, but not after Vertex treatment. Error bars represent the standard error of the mean; ** indicates a difference between means $p < 0.005$; and * indicates a difference between means $p < 0.05$.

of visual imagery processes engaged for the studied items. Our approach addressed these limitations by probing the recall of specific details of the memoranda when the participant's eyes were shut so that no external information was being processed during the memory retrieval process.

The study revealed the sensitivity of normal LTM operations to disruption by the presence of irrelevant environmental stimuli, such that the mere act of having eyes open to the surrounding environment decreases the accuracy of memory retrieval. Specifically, we found that a functional memory network involving the left hippocampus, PFC and LOC, which supports visual imagery and successful episodic retrieval when our eyes are closed, is disrupted by external distraction. This impact on performance and functional connectivity are likely mediated by capacity limitations in frontal control processes. In another study using rTMS to perturb function of the PFC node of the functional memory network, the results revealed that the left VLPFC has a direct role during retrieval of LTM in resolving competition between irrelevant external information and relevant mnemonic details. Limitations in processing capacity of prefrontal regions are a fundamental aspect in understanding the framework of cognitive control (Braver et al., 2009). The evidence in our studies revealed a critical role of the left VLPFC in the ability to reconstruct memories while interacting with our external environment.

DISTRACTION IMPAIRS CATEGORIZATION ABILITIES IN NORMAL AGING

The detrimental influence of distraction on LTM retrieval is now established, yet it is not as clear if irrelevant information impacts the underlying cognitive faculty for categorization learning. Categorization is the ability to discriminate key stimulus attributes according to abstract task rules (Ashby and Maddox, 2005), and this capability involves decision-making processes to sharpen the features of complex object representations (Freedman et al., 2003). Categorization, for example, underlies the ability to accept lemons, but reject tennis balls, as food. Categorization involves top-down control of visual attention to focus discrimination on the goal-relevant features of a stimulus during perception (Roy et al., 2010). In a new study, we examined the effects of distraction on categorization abilities in both younger and older adults, using an adaptive staircase approach to assess participants' discrimination of morphed prototype images in conditions with and without visual distractors (Wais and Gazzaley, in revision).

Psychology and neuroscience research suggest compatible models for mechanisms that integrate top-down and bottom-up processes to support sharpening of discrimination in categorization that underlies visual learning. For example, models for both a visuo-spatial sketchpad (Baddeley, 2010) and for neural activity ensembles as coherence fields (Serences and Yantis, 2006) propose that a junction in cognitive processing integrates goal-directed control of visual attention onto bottom-up representations of relevant perceptual information. This junction is thought to enable sharpening in object discrimination and may be a locus where the influence of visual distractors could interfere with top-down processes supporting visual learning. Precision of discrimination (i.e., sharpening goal-relevant representations) might be hindered when demands by top-down modulation networks that are engaged to suppress visual distraction overlap and interfere with the integration of top-down and bottom-up signals at the locus of sharpening of goal-relevant perceptual information.

Age-related effects of distractibility may also provide important insight about the processes and substrates underlying categorization abilities. A broad literature has proposed that WM decline in older adults is based on a combination of underlying factors, which include changes in basic capabilities for visual search (Hommel et al., 2004) and deficits in the ability to suppress irrelevant information (Hasher et al., 1999; Gazzaley et al., 2005a,b, 2008). Results from examinations of age-related changes for categorization capabilities are, however, equivocal (Filoteo and Maddox, 2004; Mayhew et al., 2010; Glass et al., 2012). If categorization performance is similar for both older and younger adults under well-controlled circumstances, but older adults' performance is disrupted by the presence of distractors, the finding would suggest that aging-related changes in the ability to discriminate goal-relevant perceptual features could be attributed in part to increased susceptibility to distraction.

The categorization experiment used morphed visual prototype stimuli (Ashby and Maddox, 2011), with and without distraction, to assess participants' discrimination of relevant perceptual features. Participants were one group of 19 younger adults (9 males, age 20–29 years) and one group of 20 older adults (10 males, mean age = 68.2 ± 7.2 years), all of whom were tested for normal or corrected-to-normal vision in experiment orientation. On each trial, two different prototypes of an object category (i.e., two cars or two snowboards) were presented side-by-side and followed by presentation of a morphed exemplar, which the participant endorsed as belonging to one of the two prototype categories (**Figure 5A**). Each morphed exemplar was generated by integrating the feature information from 75 to 100 significant corresponding points on the category prototypes. The morph ratio (i.e., varying in difficulty from 75:25% up to 51:49%) changed according to an adaptive staircase algorithm with feedback that held accuracy constant at approximately 70%. Higher levels of morph ratio (i.e., 70% prototype A and 30% prototype B) were easier to categorize than lower levels of morph ratio (i.e., 48% prototype A and 52% prototype B). In the distractor condition, the morphed exemplars were centered on a grayscale collage composed from fragmented views of the respective category prototypes (i.e., irrelevant visual information). Participants' categorization threshold was assessed in terms of morph ratio, and their performance was compared between plain and distractor conditions.

Morph ratio was compared as a repeated measure of condition (plain|distractor) between groups (younger|older). The results showed a main effect of group, such that younger adults categorized at a lower morph ratio (i.e., better performance) than older adults. An interaction of age × condition revealed that older adults were more susceptible to visual distraction during categorization than younger adults. Critically, comparisons between age groups showed no difference in performance in the plain condition, but older adults categorized with a significantly higher morph ratio in the distractor condition than did younger adults. Results within the group of older adults suggested that distractor exemplars were categorized with a higher morph ratio than plain exemplars. We analyzed the basis for this pattern in the results by comparing the mean distractibility index between age groups. An index for each participant was calculated as morph ratio in the distractor condition minus morph ratio in the plain condition, such that a positive value showed a disruptive effect of distractibility (**Figure 5B**). An independent samples *t*-test (assuming unequal variances) showed that distractibility during categorization was greater for older than younger adults.

The study examined for the first time, to the best of our knowledge, the impact of distraction on categorization learning. We found that distractors did not affect categorization of morphed exemplars for younger adults. This finding reveals that top-down processes engaged to enhance representations of relevant stimulus features during categorization are undisturbed when additional control resources are required to suppress processing of irrelevant bottom-up information during the distractor condition (Lavie and de Fockert, 2005). Interestingly, older adults were just as able as younger adults to categorize morphed exemplars in the plain condition, a finding that is consistent with some other rule-based categorization learning results (Filoteo and Maddox, 2004; Mayhew et al., 2010; Glass et al., 2012). The interaction of age and distraction in the results, however, showed that concurrent demands to integrate information for categorization processing and to suppress bottom-up influences from irrelevant visual information disrupted performance for older adults, but did not affect performance for younger adults.

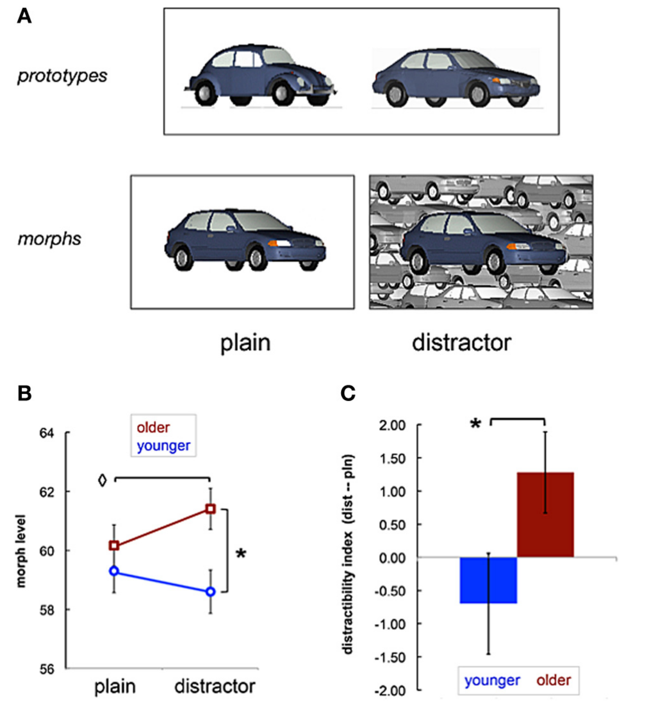

FIGURE 5 | Age-related influence of visual distraction on categorization learning. The categorization procedure **(A)** presented a side-by-side pair of category prototypes, and then an exemplar morphed from the prototypes in blocks of either plain or distractor conditions. Results **(B)** for mean categorization thresholds for groups of older and younger adults showed a main effect of age and suggested that categorization learning declined for older adults in the distractor, relative to plain conditions. Comparisons between age groups for an index of distractibility **(C)** revealed that older adults were more susceptible to the negative impact of distraction during categorization than younger adults ($p < 0.05$). Error bars indicate the standard error of the mean; ◊ indicates a trend of difference between means, $p < 0.06$; and * indicates a difference between means, $p < 0.05$.

Visual categorization is a fundamental capability in higher cognition that involves sharpening the representations of relevant stimulus features in order to accept or reject the value of a stimulus for task goals (Ashby and Maddox, 2005). Sharpening the representation of relevant stimulus features depends on reciprocal processes that integrate bottom-up stimulus-driven information, mediated by primary visual regions, with top-down task-specific information, mediated by prefrontal decision-making regions

(Freedman et al., 2003; Jiang et al., 2007). As integration of information from task goals and visual sensation proceeds with practice, learning improves the fidelity of relevant stimulus attributes so that finer and finer discriminations are successful. In this manner, selective visual attention guides improvement of the coherence of goal-relevant representations via-a-vis competing perceptual information (Serences and Yantis, 2006). Visual categorization with exemplars morphed from two prototypes is thought to be particularly demanding on the integration of top-down and bottom-up signals that successively tunes relevant stimulus features (Zeithamova et al., 2008).

Our interpretation of the results from the morphed prototype study is that categorization task demands instigated top-down control of visual attention in synchrony with updating and maintenance of WM processes (Freedman et al., 2003; Jiang et al., 2007), and older adults showed distractibility during these increased demands on top-down control that young adults did not. We propose that older adults' capability to focus visual attention on selective areas within complete object representations was diminished when concurrent demands to filter irrelevant visual information exceeded limited control resources. The locus of integration of top-down and bottom-up inputs that reciprocate through the putative hierarchy of visual perceptual processing to build an object representation has been characterized as a coherence field (Serences et al., 2005; Serences and Yantis, 2006). fMRI results show that regions of lateral parietal cortex mediate spatially selective sharpening within the coherence field associated with an object representation (Serences and Yantis, 2007).

Categorization under circumstances influenced by visual distraction involves increased processing of bottom-up visual information. The increased flow of bottom-up information may, in turn, increase demands on processes that mediate coherence fields and diminish the precision of relevant object representations. Although younger and older adults discriminated equivalent levels of morphed prototypes in our categorization condition without distraction, distractibility diminished older adults' discrimination performance. This novel finding, in particular, suggests that age-related distractibility during categorization may have more to do with interference on sharpening processes that involve the integration of visual attention and object representations than simply a deficit in top-down control of visual attention.

CONCLUSIONS

Our findings about the effects of distractibility on the fidelity of memory retrieval raised important new questions about the control of attention to visual imagery that supports LTM. Heretofore, the disruptive influence of irrelevant environmental information was understood to diminish performance on task goals served by WM (Lavie and de Fockert, 2005). The results from novel studies reviewed here revealed that LTM retrieval is also susceptible to disruption from distraction. Our findings are distinct from the literature regarding affects on LTM from divided attention or dual-tasks (Troyer et al., 1999). Specifically, we found that mnemonic details represented via visual imagery were not as accessible in conditions when perceptual distractors were present as in controlled conditions. Yet, in all conditions, participants directed their full attention to memory retrieval goals. In other words, our findings show that bottom-up processing of irrelevant environmental information diminishes the accuracy of episodic retrieval, and separate studies found that this critical cost is domain general. Moreover, there is an ageing-related increase in the cost distractibility on episodic retrieval.

Evidence from neuroimaging elucidated the functional networks supporting episodic retrieval that are susceptible to disruption from the influences of environmental distraction. Although the key nodes for networks supporting the fidelity of LTM were identified in our studies (i.e., regions of the VLPFC, MTL, and LOC), the precise locus where information from bottom-up processes associated with distraction interferes with information represented from LTM stores is, as yet, unclear. A potential substrate where perceptual information might intersect with top-down selection and tuning processes necessary for representation of episodic details is illustrated by the notion of coherence fields (Serences and Yantis, 2006). Coherence fields are thought to be mediated by functionally networked regions at of the occipital, parietal and frontal cortices (Serences and Yantis, 2007).

We also recently examined the impact of visual distraction on categorization learning, using a task that is orthogonal to LTM retrieval yet very demanding on the fidelity of information represented in immediate memory (Jiang et al., 2007). The results showed that young adults' categorization performance was not affected by visual distraction, whereas older adults were susceptible to distraction during categorization. This ageing-related deficit in filtering out irrelevant distracting information during categorization is convergent with previous findings for visual WM (Gazzaley et al., 2005a,b; Clapp and Gazzaley, 2012). It may be the case that cognitive control resources, although limited, have the capability to resolve interference from distractors during tasks of moderate effort (i.e., calling on WM), but these resources are overwhelmed when additional processes associated with episodic retrieval are required. Indeed, remembering specific details has been shown a particularly effortful cognitive load (Atkinson and Juola, 1973). Age-related distractibility during categorization, therefore, may provide meaningful insight concerning the locus of interference of distractors on the fidelity of details represented from LTM.

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REFERENCES

Ashby, F., and Maddox, W. T. (2005). Human category learning. *Ann. Rev. Psychol.* 56, 149–178. doi: 10.1146/annurev.psych.56.091103.070217

Ashby, F., and Maddox, W. T. (2011). Human category learning 2.0. *Ann. N.Y. Acad. Sci.* 1224, 147–161. doi: 10.1111/j.1749-6632.2010.05874.x

Atkinson, R., and Juola, J. (1973). "Factors influencing the speed and accuracy of word recognition," in *Attention and Performance*, ed S. Kornblum (New York, NY: Academic Press), 583–612.

Baddeley, A. (2010). Working memory. *Curr. Biol.* 20, 136–140. doi: 10.1016/j.cub.2009.12.014

Berry, A., Zanto, T., Rutman, A., Clapp, W., and Gazzaley, A. (2009). The influence of perceptual training on working memory in older adults. *J. Neurophysiol.* 102, 1779–1789. doi: 10.1152/jn.00179.2009

Blumenfeld, R., and Ranganath, C. (2006). Dorsolateral prefrontal cortex promotes long-term memory formation through its role in working memory organization. *J. Neurosci.* 26, 916–925. doi: 10.1523/JNEUROSCI.2353-05.2006

Braver, T., Paxton, J., Locke, H., and Barch, D. (2009). Flexible neural mechanisms of cognitive control within human prefrontal cortex. *Proc. Natl. Acad. Sci. U.S.A.* 106, 7351–7356. doi: 10.1073/pnas.0808187106

Chalfonte, B., and Johnson, M. (1996). Feature memory and binding in young and older adults. *Mem. Cogn.* 24, 403–416. doi: 10.3758/BF03200930

Clapp, W., and Gazzaley, A. (2012). Distinct mechanisms for the impact of distraction and interruption on working memory in aging. *Neurobiol. Aging* 33, 134–148. doi: 10.1016/j.neurobiolaging.2010.01.012

Clapp, W., Rubens, M., and Gazzaley, A. (2010). Mechanisms of working memory disruption by external interference. *Cereb. Cortex* 20, 859–872. doi: 10.1093/cercor/bhp150

Craik, F. (2002). "Human memory and aging," in *Psychology at the Turn of the Millennium*, eds L. Baeckman and C. V. Hofsten (Hove: Psychology Press), 262–280.

De Fockert, J. W., Rees, G., Frith, C. D., and Lavie, N. (2001). The role of working memory in visual selective attention. *Science* 291, 1803–1806. doi: 10.1126/science.1056496

Desimone, R. (1998). Visual attention mediated by biased competition in extrastriate visual cortex. *Philos. Trans. R. Soc. Lond. B Biol. Sci.* 353, 1245–1255. doi: 10.1098/rstb.1998.0280

Dobbins, I., and Wagner, A. (2005). Domain-general and domain-sensitive prefrontal mechanisms for recollecting events and detecting novelty. *Cereb. Cortex* 15, 1768–1778. doi: 10.1093/cercor/bhi054

Ferguson, S., Hashtroudi, S., and Johnson, M. (1992). Age differences in using source-relevant cues. *Psychol. Aging* 7, 443–455. doi: 10.1037/0882-7974.7.3.443

Fernandes, M., Pacurar, A., and Moscovitch, M. (2006). Neural correlates of auditory recognition under full and divided attention in younger and older adults. *Neuropsychologia* 44, 2452–2464. doi: 10.1016/j.neuropsychologia.2006.04.020

Fernandes, M. A., and Moscovitch, M. (2000). Divided attention and memory: evidence of substantial interference effects at retrieval and encoding. *J. Exp. Psychol. Gen.* 129, 155–176. doi: 10.1037/0096-3445.129.2.155

Filoteo, J., and Maddox, W. T. (2004). A quantitative model-based approach to examining aging effects on information-integration category learning. *Psychol. Aging* 19, 171–182. doi: 10.1037/0882-7974.19.1.171

Freedman, D., Riesenhuber, M., Poggio, T., and Miller, E. (2003). A comparison of primate prefrontal and inferior temporal cortices during visual categorization. *J. Neurosci.* 23, 5235–5246.

Gazzaley, A., Clapp, W., Kelley, J., McEvoy, K., Knight, R., and D'Esposito, M. (2008). Age-related top-down suppression deficit in the early stages of cortical visual memory processing. *Proc. Natl. Acad. Sci. U.S.A.* 105, 13122–13126. doi: 10.1073/pnas.0806074105

Gazzaley, A., Cooney, J., McEvoy, K., Knight, R., and D'Esposito, M. (2005b). Top-down enhancement and suppression of the magnitude and speed of neural activity. *J. Cogn. Neurosci.* 17, 507–517. doi: 10.1162/0898929053279522

Gazzaley, A., Cooney, J., Rissman, J., and D'Esposito, M. (2005a). Top-down suppression deficit underlies working memory impairment in normal aging. *Nat. Neurosci.* 8, 1298–1300. doi: 10.1038/nn1543

Ghazanfar, A., and Schroeder, C. (2006). Is neocortex essentially multisensory? *Trends Cogn. Sci.* 10, 278–285. doi: 10.1016/j.tics.2006.04.008

Glass, B., Chotibut, T., Pacheco, J., Schnyer, D., and Maddox, W. T. (2012). Normal aging and the dissociable prototype learning systems. *Psychol. Aging* 27, 120–128. doi: 10.1037/a0024971

Glenberg, A., Schroeder, J., and Robertson, D. (1998). Averting the gaze disengages the environment and facilitates remembering. *Mem. Cogn.* 26, 651–658. doi: 10.3758/BF03211385

Hasher, L., Zacks, R., and May, C. (1999). "Inhibitory control, circadian arousal and age," in *Attention and Performance XVII*, eds D. Gopher and A. Koriat (Cambridge, MA: MIT Press), 653–675.

Hashtroudi, S., Johnson, M. K., and Chrosniak, L. (1990). Aging and qualitative characteristics of memories for perceived and imagined complex events. *Psychol. Aging* 5, 119–126. doi: 10.1037/0882-7974.5.1.119

Henkel, L., Johnson, M., and Leonardis, D. (1998). Aging and source monitoring: cognitive processes and neuropsychological correlates. *J. Exp. Psychol. Gen.* 127, 251–268. doi: 10.1037/0096-3445.127.3.251

Hommel, B., Li, K., and Li, S. C. (2004). Visual search across the life span. *Dev. Psychol.* 40, 545–558. doi: 10.1037/0012-1649.40.4.545

Jacoby, L. (1991). A process dissociation framework: separating automatic from intentional uses of memory. *J. Mem. Lang.* 30, 513–451. doi: 10.1016/0749-596X(91)90025-F

Jiang, X., Bradley, E., Rini, R., Zeffiro, T., VanMeter, J., and Riesenhuber, M. (2007). Categorization training results in shape and category-selective human neural plasticity. *Neuron* 53, 891–903. doi: 10.1016/j.neuron.2007.02.015

Johnson, J. D., McDuff, S. G., Rugg, M. D., and Norman, K. A. (2009). Recollection, familiarity, and cortical reinstatement: a multivoxel pattern analysis. *Neuron* 63, 697–708. doi: 10.1016/j.neuron.2009.08.011

Johnson, J. D., and Rugg, M. D. (2007). Recollection and the reinstatement of encoding-related cortical activity. *Cereb. Cortex* 17, 2507–2515. doi: 10.1093/cercor/bhl156

Kahn, I., Davachi, L., and Wagner, A. (2004). Functional-neuroanatomic correlates of recollection: implications for models of recognition memory. *J. Neurosci.* 24, 4172–4180. doi: 10.1523/JNEUROSCI.0624-04.2004

Lavie, N. (2005). Distracted and confused? Selective attention under load. *Trends Cogn. Sci.* 9, 75–82. doi: 10.1016/j.tics.2004.12.004

Lavie, N., and de Fockert, J. (2005). The role of working memory in attentional capture. *Psychon. Bull. Rev.* 12, 669–674. doi: 10.3758/BF03196756

Lavie, N., Hirst, A., De Fockert, J., and Viding, E. (2004). Load theory of selective attention and cognitive control. *J. Exp. Psychol. Gen.* 133, 339–354. doi: 10.1037/0096-3445.133.3.339

Law, J., Flanery, M., Wirth, S., Yanike, M., Smith, A., Frank, L., et al. (2005). Functional magnetic resonance imaging activity during the gradual acquisition and expression of paired-associate memory. *J. Neurosci.* 25, 5720–5729. doi: 10.1523/JNEUROSCI.4935-04.2005

Li, J., Morcom, A., and Rugg, M. (2004). The effects of age on the neural correlates of successful episodic retrieval: an ERP study. *Cogn. Affect. Behav. Neurosci.* 4, 279–293. doi: 10.3758/CABN.4.3.279

Macmillan, N., and Creelman, C. (2005). *Detection Theory: A User's Guide, 2nd Edn*. New Jersey, NJ: L Erlbaum Associates, Inc.

Mayhew, S., Li, S., Storrar, J., Tsvetanov, K., and Kourtzi, Z. (2010). Learning shapes the representation of visual categories in the aging human brain. *J. Cogn. Neurosci.* 22, 2899–2912. doi: 10.1162/jocn.2010.21415

Naveh-Benjamin, M., Hussain, Z., Guez, J., and Bar-On, M. (2003). Adult age differences in episodic memory: further support for an associative-deficit hypothesis. *J. Exp. Psychol. Learn. Mem. Cogn.* 29, 826–837. doi: 10.1037/0278-7393.29.5.826

Pashler, H., and Shiu, L. (1999). Do images involuntarily trigger search? A test of Pillsbury's hypothesis. *Psychon. Bull. Rev.* 6, 445–448. doi: 10.3758/BF03210833

Perfect, T., Andrade, J., and Eagan, I. (2011). Eye closure reduces the cross-modal memory impairment caused by auditory distraction. *J. Exp. Psychol. Learn. Mem. Cogn.* 37, 1008–1013. doi: 10.1037/a0022930

Rainer, G., Asaad, W. F., and Miller, E. K. (1998). Selective representation of relevant information by neurons in the primate prefrontal cortex. *Nature* 393, 577–579. doi: 10.1038/31235

Ranganath, C., Cohen, M., Dam, C., and D'Esposito, M. (2004). Inferior temporal, prefrontal, and hippocampal contributions to Visual working memory maintenance and associative memory retrieval. *J. Neurosci.* 24, 3917–3925. doi: 10.1523/JNEUROSCI.5053-03.2004

Roy, J., Riesenhuber, M., Poggio, T., and Miller, E. (2010). Prefrontal cortex activity during flexible categorization. *J. Neurosci.* 30, 8519–8528. doi: 10.1523/JNEUROSCI.4837-09.2010

Serences, J. T., Shomstein, S., Leber, A. B., Golay, X., Egeth, H. E., and Yantis S. (2005). Coordination of voluntary and stimulus-driven attentional control in human cortex. *Psycholg. Sci.* 16, 114–122. doi: 10.1111/j.0956-7976.2005.00791.x

Serences, J. T., and Yantis, S. (2006). Selective visual attention and perceptual coherence. *Trends Cogn. Sci.* 10, 38–45. doi: 10.1016/j.tics.2005.11.008

Serences, J. T., and Yantis, S. (2007). Spatially selective representations of voluntary and stimulus-driven attentional priority in human occipital, parietal, and frontal cortex. *Cereb. Cortex* 17, 284–293. doi: 10.1093/cercor/bhj146

Troyer, A., Wincour, G., Craik, F., and Moscovitch, M. (1999). Source memory and divided attention: reciprocal costs to primary and secondary tasks. *Neuropsychology* 13, 467–474. doi: 10.1037/0894-4105.13.4.467

Vredeveldt, A., Hitch, G., and Baddeley, A. (2011). Eyeclosure helps memory by reducing cognitive load and enhancing visualisation. *Mem. Cogn.* 39, 1253–1263. doi: 10.3758/s13421-011-0098-8

Wais, P. E. (2011). Hippocampal signals for strong memory when associative memory is available and when it is not. *Hippocampus* 21, 9–21. doi: 10.1002/hipo.20716

Wais, P. E., and Gazzaley, A. (2011). The impact of auditory distraction on retrieval of visual memories. *Psychono. Bull. Rev.* 18, 1090–1097. doi: 10.3758/s13423-011-0169-7

Wais, P. E., Kim, O., and Gazzaley, A. (2012a). Distractibility during episodic retrieval is exacerbated by perturbation of left ventrolateral prefrontal cortex. *Cereb. Cortex*, 22, 717–724. doi: 10.1093/cercor/bhr160

Wais, P. E., Martin, G., and Gazzaley, A. (2012b). The impact of visual distraction on episodic retrieval in older adults. *Brain Res.* 1430, 78–85. doi: 10.1016/j.brainres.2011.10.048

Wais, P. E., Rubens, M., Boccanfuso, J., and Gazzaley, A. (2010). Neural mechanisms underlying the impact of visual distraction on retrieval of long-term memory. *J. Neurosci.* 30. 8541–8550. doi: 10.1523/JNEUROSCI.1478-10.2010

Wheeler, M. E., and Buckner, R. L. (2004). Functional-anatomic correlates of remembering and knowing. *Neuroimage* 21, 1337–1349. doi: 10.1016/j.neuroimage.2003.11.001

Zanto, T., and Gazzaley, A. (2009). Neural suppression of irrelevant information underlies optimal working memory performance. *J. Neurosci.* 29, 3059–3066. doi: 10.1523/JNEUROSCI.4621-08.2009

Zeithamova, D., Maddox, W., and Schnyer, D. (2008). Dissociable prototype learning systems: evidence from brain imaging and behavior. *J. Neurosci.* 28, 13194–13201. doi: 10.1523/JNEUROSCI.2915-08.2008

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The disruptive – and beneficial – effects of distraction on older adults' cognitive performance

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Older adults' decreased ability to inhibit irrelevant information makes them especially susceptible to the negative effects of simultaneously occurring distraction. For example, older adults are more likely than young adults to process distraction presented during a task, which can result in delayed response times, decreased reading comprehension, disrupted problem solving, and reduced memory for target information. However, there is also some evidence that the tendency to process distraction can actually facilitate older adults' performance when the distraction is congruent with the target information. For example, congruent distraction can speed response times, increase reading comprehension, benefit problem solving, and reduce forgetting in older adults. We review data showing that incongruent distraction can harm older adults' performance, as well as evidence suggesting that congruent distraction can play a supportive role for older adults by facilitating processing of target information. Potential applications of distraction processing are also discussed.

Keywords: aging, attention regulation, distraction, inhibition, facilitation

People often prefer to work in quiet, distraction-free environments when doing cognitively demanding tasks such as reading, driving, or solving a puzzle. Quiet typically improves task performance because it allows a person to concentrate their attentional resources on the task at hand (Kahneman, 1973), possibly by minimizing the amount of interference created by irrelevant information (Hasher and Zacks, 1988).

The desire to work in a quiet environment may increase with age as people become even more susceptible to the disruptive effects of distraction (Hasher and Zacks, 1988). This idea is supported by a good deal of laboratory based evidence, from simple response time measures to more complex tasks involving problem solving and reading for comprehension, all showing that irrelevant distraction has an especially negative effect on older adults' performance.

Contrary to popular belief, however, the consequences of older adults' tendency to process distraction are not always negative. In this paper, we review evidence that the content of distracting information, specifically its relevance to target information, determines whether it will help or hinder older adults' performance. Following a brief section on potential neural underpinnings of this phenomenon, we begin with a review of the abundant evidence showing that incongruent distraction is especially disruptive in old age. Next, we turn to the growing literature showing that congruent distraction can actually benefit older adults and, where gaps in the literature exist, we make predictions for future results based on extant evidence. Finally, we suggest some possible ways in which beneficial distraction may help older adults function optimally in the real world.

NEURAL UNDERPINNINGS OF DISTRACTER PROCESSING

The neural basis for this age-related inhibitory deficit is gradually being revealed through the use of neuroimaging techniques. Functional MRI studies have implicated a widespread network of frontal and parietal brain regions as the basis for top-down attentional control in young adults (Corbetta and Shulman, 2002; Vincent et al., 2008; Spreng et al., 2010). This frontoparietal network, which includes the rostral prefrontal cortex, and inferior parietal cortex, is recruited by young adults when they are told to ignore salient distracters, and its activation is associated with decreased priming for distraction (Campbell et al., 2012). However, connectivity between these regions is reduced in older adults (Madden et al., 2010; Campbell et al., 2012; Li et al., 2012), who also show a corresponding increase in priming for distraction (Campbell et al., 2012). Therefore, a breakdown in the intrinsic connectivity of the frontoparietal control network with age may dysregulate top-down attention (Campbell et al., 2012), resulting in the processing of distracters by older adults. In many scenarios, increased processing of distracters is detrimental to cognitive performance; however, evidence shows that processing non-target stimuli that are congruent with task goals can in fact facilitate perception of target stimuli, leading to enhanced task performance (e.g., May, 1999; Yang and Hasher, 2007; Mozolic et al., 2012).

WHEN DISTRACTION HARMS

RESPONSE TIMES

Older adults' difficulty in ignoring distracting information is perhaps most apparent in their performance on typical tasks of interference control, such as the Stroop (1935) and flanker

(Eriksen and Eriksen, 1974) tasks. In these tasks, the critical trials contain distraction that is in direct competition with the required response. Performance on these trials compared to control trials is an index of distracter processing. As expected, older adults show a disproportionate slowing on interference trials compared to younger adults in both the Stroop (Spieler et al., 1996; West and Alain, 2000) and flanker (Zeef et al., 1996) tasks. Older adults are also slowed by distraction on tasks that are not typically thought of as containing interference. For example, Lustig et al. (2006) showed that older adults were faster to indicate whether or not two sets of letters are the same (e.g., RXLTVY_RXLTVY) when only one pair was presented at a time compared to when many pairs were presented simultaneously. It is noteworthy that this manipulation did not affect the response times of younger adults. Interestingly, this result suggests that older adults' response times may be overestimated in any test that contains visual clutter, due to their reduced ability to filter out irrelevant information (Hasher and Zacks, 1988).

Auditory and even multimodal distraction can also be disruptive to older adults. For example, older adults show larger auditory Stroop (e.g., Sommers and Huff, 2003) and Simon (e.g., Pick and Proctor, 1999) effects than do younger adults. When participants were asked to make a lexical judgment about a spoken word and ignore its tone of voice, older adults were slower to respond to a word that was spoken in an incongruent tone of voice (e.g., "annoyed," spoken in a happy tone) than a congruent tone of voice (e.g., "annoyed," spoken in an annoyed tone), but no similar slowing effect was found in younger adults (Wurm et al., 2004). Additionally, older adults may be especially susceptible to distraction presented in a different modality from target information (Guerreiro et al., 2013b). For instance, older adults' responses on a visual digit categorization task (i.e., "Is this digit odd or even?") were reported to be disproportionately slowed when trials were preceded by an oddball noise compared to a standard noise with which they were very familiar (Parmentier and Andrés, 2010, but see Guerreiro et al., 2013a).

In light of evidence that older adults are more susceptible than young adults to distraction in multiple modalities, as well as across modalities, it is likely that increased distracter processing reflects an age-related decline in a central inhibitory mechanism (Hasher and Zacks, 1988), rather than a decrease in the integrity of any one sensory system. Further support for this idea comes from a recent finding showing that older adults' resistance to auditory distraction in a speech-in-noise task can be predicted by their resistance to visual distraction in a Stroop task, above and beyond the predictive effect of hearing loss (Janse, 2012).

PROBLEM SOLVING

The findings reviewed above suggest that distraction can disrupt older adults' performance in a wide variety of tasks. One can then ask how much older adults actually know about the irrelevant distraction. Work by May (1999) shed light on this question by showing that semantically misleading distracters can impair older adults' performance on a problem solving task. In this study, older and younger adults performed the Remote Associates Task (Mednick, 1962), in which they were asked to identify a word that connects three cue words (e.g., SHIP, OUTER, CRAWL; answer: space) while ignoring concurrently presented distracter words. When distracter words were misleading, that is, when they were related to the incorrect interpretation of the cue word [e.g., ocean (SHIP), inner (OUTER), baby (CRAWL)], older adults' problem solving suffered. Thus, older adults are not just slowed by response-incompatible distraction; they also conceptually process the meaning of distracters and this can impact higher order tasks like problem solving.

COMPREHENSION AND MEMORY

The tendency to conceptually process distracters also has implications for reading comprehension. There is considerable evidence that older adults have more difficulty reading written passages that are interspersed with visually distinct distracting words, especially when the distracting words are semantic competitors of words in the passage (Connelly et al., 1991; Duchek et al., 1998; Darowski et al., 2008). After reading such passages, older adults are also more likely than younger adults to incorrectly answer comprehension questions with the distracting words (McGinnis, 2012). This finding suggests that irrelevant information processed during reading may distort older adults' interpretation of text. Although passages with deliberately inserted distracter words are uncommon in the real world, having the television or radio on while reading could influence older adults' comprehension of text, which might be especially problematic if they are reading information with medical or legal relevance.

Perhaps not surprisingly, distraction likewise influences memory of to-be-learned information. For example, older adults but not younger adults showed reduced free recall of a text when it was interspersed with distracting words compared to when it was not (Mund et al., 2012). In a similar task in the auditory domain, older but not younger adults showed worse recall of spoken sentences masked by meaningful distracter speech compared to spoken sentences masked by random word strings (Tun et al., 2002). In a cross-modal study in which participants memorized written passages while listening to irrelevant distracter speech, older adults made more intrusions that were related to the distracter speech in their recollection of the passages than did younger adults (Bell et al., 2008). Together, these findings suggest that processing irrelevant distraction during encoding, as older adults do, cannot only reduce memory for targets, but also contaminate memory by coloring it with the semantic content of the distraction.

Just as distraction at encoding has an especially deleterious effect on memory for older adults, so does distraction at retrieval. Older adults but not younger adults remembered fewer details about previously studied objects when they were fixating their gaze on an unrelated distracter picture during retrieval than when they were fixating on a gray screen (Wais et al., 2012). Older adults seem to be more susceptible to interference from incongruent distraction at both encoding and retrieval stages of memory (but see Fernandes and Moscovitch, 2003).

In summary, incongruent or irrelevant distraction can be particularly disruptive to older adults' performance on a wide range of laboratory tasks. The negative effect of distraction on older adults also has real world consequences, given that impaired attentional control in old age has been associated with an increased risk of falls (Mirelman et al., 2012; Amboni et al., 2013), traffic accidents (Nagamatsu et al., 2011; Neider et al., 2011), and driver errors (Hoffman et al., 2005; Thompson et al., 2012).

WHEN DISTRACTION HELPS

There is substantial evidence, then, that older adults process distraction both perceptually and conceptually, and this tendency frequently impairs their cognitive performance relative to that of younger adults'. There are also findings showing that older adults can actually benefit from the presence of distraction, an effect that can be seen when the distraction is congruent with the task that they are performing. The benefits of distraction processing have received noticeably less empirical attention than have the costs of distraction processing, so, where appropriate, we also identify gaps in the literature and offer our predictions for future work in this area.

REACTION TIMES

In simple target detection tasks, older adults have been shown to reliably benefit from multisensory targets more than young adults do (Mozolic et al., 2012). Remarkably, older adults' response times in detecting visual stimuli onset were faster than younger adults' responses when an auditory tone was played at target onset, even though no age differences in unisensory target response times were seen (Peiffer et al., 2007). In another study, older adults' saccades toward visual targets were speeded to a greater degree than younger adults' when a spatially congruent tone was played at target onset, and this was true even in the presence of visual distraction (Campbell et al., 2010).

Perceptual facilitation by distraction can sometimes be seen in older adults' Stroop performance as well. Spieler et al. (1996) found a numerical but not statistically significant speeding of reaction times on congruent trials compared to no distraction trials in older but not younger adults. Interestingly, the facilitation of response time by congruent distraction was markedly increased in patients with Alzheimer's disease, which is also characterized by a decrease in executive functions including resistance to distraction (Baddeley et al., 2001). These results suggest that the capture of attention by distraction in older adults happens at a relatively low level, and can benefit target detection in older adults when the distraction is congruent with the required response.

Older adults' response times can also be speeded by the presence of a distracter that is conceptually congruent with the target. The conceptual congruency between target and distracter should facilitate target processing to the extent that an individual processes the distraction. Yang and Hasher (2007) demonstrated precisely this effect. They measured the time it took younger and older adults to indicate whether two successively presented words were semantically similar, depending on whether the first word was superimposed over a semantically congruent or incongruent picture that was irrelevant to the task. They found that older adults showed a much greater facilitation effect for the congruent pictures than the younger adults did. Therefore, while response times in old age can be slowed by irrelevant distraction, the evidence reviewed here suggests that they can also be speeded by congruent distraction.

PROBLEM SOLVING

The tendency to conceptually process distraction can also benefit higher order cognition, such as problem solving. In the previously described study by May (1999), older adults' performance on the Remote Associates Test was shown to be improved in a condition where the distracter word primed the *correct* interpretation of the cue words. For example, for the cue words SHIP, OUTER, CRAWL, the solution is "space." When distracter words primed the correct interpretation of the words, [e.g., rocket (SHIP), atmosphere (OUTER), or attic (CRAWL)], the older adults were more likely to solve the problem than when the distraction primed the incorrect interpretation of the words, even though they reported not looking at the distracters. In this way, problem solving was enhanced by capitalizing on older adults' tendency to conceptually process distraction. Interestingly, older adults' problem solving was also enhanced on the Remote Associates Task when the solution words appeared as distraction in a previous task (Kim et al., 2007), suggesting that older adults retain the semantic content of distraction for some length of time even after the distraction has been removed.

COMPREHENSION AND MEMORY

If unintentionally processing task-congruent, non-target items can enhance problem solving, then the same might be true for reading comprehension. Surprisingly, given the large number of aging studies that have used the reading with distraction paradigm, the effect of semantically congruent distracters on reading comprehension in this paradigm has yet to be tested. Based on the May (1999) data reviewed above, one would predict that older adults' reading times and/or comprehension of a written passage may be improved if distracters were synonyms of important words in the passage instead of semantic competitors as in previous studies (e.g., Connelly et al., 1991).

A few studies have tested whether older adults' reading comprehension is improved by the addition of aids such as illustrative graphics or simultaneous listening while reading. In one such study, Griffin and Wright (2009) asked younger and older adults to read informational leaflets containing embellishing (i.e., non-informative) graphics, explanatory (i.e., conceptually relevant) graphics, or just text and no graphics, and tested the time they took to answer comprehension questions about the material. They found that there was an age-related slowing in answering questions in the embellishing graphics condition, but that the age effect was eliminated when the graphics were explanatory. These data suggest that the conceptually related graphics provided some facilitation for older adults' comprehension, even though it was not sufficient to improve their performance beyond the level seen in the no graphics condition. However, the graphics in this study were presented in the margins of the leaflets, so perhaps reducing the spatial distance between the text and the graphics would increase older adults' processing of the graphics, thereby enhancing comprehension even further. This prediction, if supported, could have obvious practical benefits for older adults' everyday reading.

Given that older people seem to benefit more from multisensory integration (Mozolic et al., 2012), they may also find it easier to read written information while concurrently listening to it. Wright et al. (2008) tested this prediction. Participants performed an "open-book" reading test on the computer and had the option of choosing whether or not they would like to simultaneously listen to the information while reading it. The researchers reported that 41% of older participants chose the listening option regularly. There was no difference in test accuracy or speed between listeners and non-listeners, but pre-test group differences in cognitive ability might have obscured any benefit of listening. This study suggests that a sizeable proportion of older adults, especially those with lower cognitive capabilities, may prefer to learn information presented in multiple modalities simultaneously instead of simply reading written text.

The findings reviewed above (e.g., May, 1999; Yang and Hasher, 2007) make it clear that the processing of target items can be influenced by the conceptual relevance of distracter items. Therefore, it may also be possible that distracters can influence the *depth* of target processing. Since the depth of target processing has been shown to influence retention of to-be-remembered items (Craik and Lockhart, 1972; Craik and Tulving, 1975), it may be possible to improve memory in older adults by manipulating the nature of distraction at encoding. For example, when learning a list of words in the presence of distraction, the depth with which to-be-remembered words are processed could conceivably be influenced by the nature of the relationship between the to-be-remembered words and distracter words. If a distracter cued a shallow feature of the to-be-remembered word (e.g., its font), it may facilitate a shallow processing of the word. On the other hand, if the distracter cued a conceptual feature of the to-be-remembered word (e.g., its closest semantic associate) then the word may be processed more deeply, and therefore it may be better remembered.

Although this specific prediction has not been tested, one study to date does support the idea that memory can be improved in older adults through the processing of congruent distraction. In three experiments, Biss et al. (2013) had older and younger adults learn and recall a list of words, followed by a surprise delayed recall test. In the delay before the final recall, participants performed a working memory task in which some of the words from the initial memory task were repeated as distraction. Older adults, but not younger adults, showed reduced forgetting of the words that were repeated as distraction compared to words that did not repeat. Thus, congruent distraction can improve memory by reactivating, or facilitating processing of, target information in older adults.

POTENTIAL APPLICATIONS

In the following section we offer some speculations about real-world benefits that might result from the presence of congruent distraction in the lives of older people.

TEACHING AND INSTRUCTION

Learning a new skill and engaging in new activities are among the most effective ways that people can preserve their cognitive functioning in old age (Park et al., 2014). Therefore, it is critical that instructional information intended for an older audience is created in such a way that facilitates optimal understanding. Based on the findings of Griffin and Wright (2009), it seems that instructional materials should be straightforward and free of unnecessary visual clutter, including graphics, unless the distracting information reinforces the concepts being taught.

MEMORY

Since there is much empirical evidence to suggest that older adults encode the content of distraction (e.g., Bell et al., 2008), and that distraction can strengthen the representation of memory traces (Biss et al., 2013), it is possible that older adults' memory might actually be improved by the addition of non-target information to their environment, as long as it reinforces the material they wish to remember. For example, if an older individual wished to remember vocabulary words from a foreign language they are learning, they may wish to play a foreign language radio station in the background while they are commuting or doing housework. An older person may attend to the background sounds more than a young person would, and this may serve to implicitly strengthen their memory of the foreign word meanings they wish to remember.

DRIVING

Age-related slowing of response time is one of the major safety concerns for drivers over 65 years of age (Anstey et al., 2005). However, older adults' response times have been shown to be faster than those of young adults when the target is presented in multiple modalities at the same time (Peiffer et al., 2007). Therefore, it is possible that the addition of an automated in-vehicle system that delivers multisensory collision avoidance signals, such as the one proposed by Ho et al. (2007), may be especially beneficial for older drivers. Additionally, the presence of environmental support cues, such as a colored light in the side mirror indicating the safety of a lane change, may provide implicit guidance for older adults' decision making and serve to prevent accidents. However, in-vehicle assistance systems designed for older drivers need to be created to reduce the amount of irrelevant distraction, not increase it. Systems that require extensive interaction with the driver or provide information that is not of direct relevance, however, well-intentioned, may actually impair the performance of older adults who are more susceptible than young adults to off-topic distraction (Young and Regan, 2007).

CONCLUSION

The evidence reviewed in this paper suggests that distraction is a double-edged sword for older adults; it can disrupt cognitive performance when incongruent with the task at hand, but it can facilitate performance when congruent. In other words, the notion that all distraction is disruptive is not necessarily true for older adults, who are able to pick up on helpful distraction and use it to their advantage in a way that younger adults do not. Therefore, if one's goal is to modify environmental conditions so as to optimize cognitive performance, then one should consider age as well as distracter congruence in this process.

However, it is also worth noting that older adults differ widely in their ability to inhibit irrelevant information (Healey et al., 2013), and thus may differ in their ability to use relevant distraction to their advantage. There has been some suggestion in the literature that older individuals with high working memory scores are better at suppressing irrelevant information than are individuals with low working memory scores (Gazzaley et al., 2005; Healey et al., 2013), so perhaps older individuals with impaired working memory would experience the greatest benefit from congruent distraction. There is also some evidence that older adults may have an intuitive sense about whether or not they would benefit from the presence of congruent distraction (Wright et al., 2008), so perhaps the best option is to provide a choice to older individuals so that they can perform in the way that feels most comfortable to them.

REFERENCES

Amboni, M., Barone, P., and Hausdorff, J. M. (2013). Cognitive contributions to gait and falls: evidence and implications. *Mov. Disord.* 28, 1520–1533. doi: 10.1002/mds.25674

Anstey, K. J., Wood, J., Lord, S., and Walker, J. G. (2005). Cognitive, sensory and physical factors enabling driving safety in older adults. *Clin. Psychol. Rev.* 25, 45–65. doi: 10.1016/j.cpr.2004.07.008

Baddeley, A. D., Baddeley, H. A., Bucks, R. S., and Wilcock, G. K. (2001). Attentional control in Alzheimer's disease. *Brain* 124, 1492–1508. doi: 10.1093/brain/124.8.1492

Bell, R., Buchner, A., and Mund, I. (2008). Age-related differences in irrelevant-speech effects. *Psychol. Aging* 23, 377–391. doi: 10.1037/0882-7974.23.2.377

Biss, R. K., Ngo, K. J., Hasher, L., Campbell, K. L., and Rowe, G. (2013). Distraction can reduce age-related forgetting. *Psychol. Sci.* 24, 448–455. doi: 10.1177/0956797612457386

Campbell, K. L., Al-Aidroos, N., Fatt, R., Pratt, J., and Hasher, L. (2010). The effects of multisensory targets on saccadic trajectory deviations: eliminating age differences. *Exp. Brain Res.* 201, 385–392. doi: 10.1007/s00221-009-2045-5

Campbell, K. L., Grady, C. L., Ng, C., and Hasher, L. (2012). Age differences in the frontoparietal cognitive control network: implications for distractibility. *Neuropsychologia* 50, 2212–2223. doi: 10.1016/j.neuropsychologia.2012.05.025

Connelly, S. L., Hasher, L., and Zacks, R. T. (1991). Age and reading: the impact of distraction. *Psychol. Aging* 6, 533–541. doi: 10.1037/0882-7974.6.4.533

Corbetta, M., and Shulman, G. L. (2002). Control of goal-directed and stimulus-directed attention in the brain. *Nat. Rev. Neurosci.* 3, 201–215. doi: 10.1038/nrn755

Craik, F. I., and Lockhart, R. S. (1972). Levels of processing: a framework for memory research. *J. Verbal. Learning. Verbal Behav.* 11, 671–684. doi: 10.1016/S0022-5371(72)80001-X

Craik, F. I., and Tulving, E. (1975). Depth of processing and the retention of words in episodic memory. *J. Exp. Psychol. Gen.* 104, 268–294. doi: 10.1037/0096-3445.104.3.268

Darowski, E. S., Helder, E., Zacks, R. T., Hasher, L., and Hambrick, D. Z. (2008). Age-related differences in cognition: the role of distraction control. *Neuropsychology* 22, 638–644. doi: 10.1037/0894-4105.22.5.638

Duchek, J. M., Balota, D. A., and Thessing, V. C. (1998). Inhibition of visual and conceptual information during reading in healthy aging and Alzheimer's disease. *Aging, Neuropsychol. Cogn.* 5, 169–181. doi: 10.1076/anec.5.3.169.616

Eriksen, B. A., and Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Percept. Psychophys.* 16, 143–149. doi: 10.3758/BF03203267

Fernandes, M. A., and Moscovitch, M. (2003). Interference effects from divided attention during retrieval in younger and older adults. *Psychol. Aging* 18, 219–230. doi: 10.1037/0882-7974.18.2.219

Gazzaley, A., Cooney, J. W., Rissman, J., and D'Esposito, M. (2005). Top-down suppression deficit underlies working memory impairment in normal aging. *Nat. Neurosci.* 8, 1298–1300. doi: 10.1038/nn1543

Griffin, J., and Wright, P. (2009). Older readers can be distracted by embellishing graphics in text. *Eur. J. Cogn. Psychol.* 21, 740–757. doi: 10.1080/09541440802155627

Guerreiro, M. J. S., Adam, J. J., and Van Gerven, P. W. M. (2013a). Aging and response interference across sensory modalities. *Psychon. Bull. Rev.* doi: 10.3758/s13423-013-0554-5 [Epub ahead of print].

Guerreiro, M. J. S., Murphy, D. R., and Van Gerven, P. W. M. (2013b). Making sense of age-related distractibility: the critical role of sensory modality. *Acta Psychol.* 142, 184–194. doi: 10.1016/j.actpsy.2012.11.007

Hasher, L., and Zacks, R. T. (1988). "Working memory, comprehension, and aging: A review and a new view," in *The Psychology of Learning and Motivation*, Vol. 22, ed. G. H. Bower (New York: Academic Press), 193–225.

Healey, M. K., Ngo, K. J., and Hasher, L. (2013). Below-baseline suppression of competitors during interference resolution by younger but not older adults. *Psychol. Sci.* 24, doi: 10.1177/0956797613501169

Ho, C., Reed, N., and Spence, C. (2007). Multisensory in-car warning signals for collision avoidance. *Hum. Factors* 49, 1107–1114. doi: 10.1518/001872007X249965

Hoffman, L., McDowd, J. M., Atchley, P., and Dubinsky, R. (2005). The role of visual attention in predicting driving impairment in older adults. *Psychol. Aging* 20, 610–622. doi: 10.1037/0882-7974.20.4.610

Janse, E. (2012). A non-auditory measure of interference predicts distraction by competing speech in older adults. *Aging Neuropsychol. Cogn.* 19, 741–758. doi: 10.1080/13825585.2011.652590

Kahneman, D. (1973). *Attention and Effort*. Englewood Cliffs, NJ: Prentice-Hall.

Kim, S., Hasher, L., and Zacks, R. T. (2007). Aging and a benefit of distractibility. *Psychon. Bull. Rev.* 14, 301–305. doi: 10.3758/BF03194068

Li, L., Gratton, C., Fabiani, M., and Knight, R. T. (2012). Age-related frontoparietal changes during the control of bottom-up and top-down attention: an ERP study. *Neurobiol. Aging* 34, 477–488. doi: 10.1016/j.neurobiolaging.2012.02.025

Lustig, C., Hasher, L., and Tonev, S. T. (2006). Distraction as a determinant of processing speed. *Psychon. Bull. Rev.* 13, 619–625. doi: 10.3758/BF03193972

Madden, D. J., Costello, M. C., Dennis, N. A., Davis, S. W., Shepler, A. M., Spaniol, J., et al. (2010). Adult age differences in functional connectivity during executive control. *Neuroimage* 52, 643–657. doi: 10.1016/j.neuroimage.2010.04.249

May, C. P. (1999). Synchrony effects in cognition: the costs and a benefit. *Psychon. B. Rev.* 6, 142–147. doi: 10.3758/BF03210822

McGinnis, D. (2012). Susceptibility to distraction during reading in young, young-old, and old-old adults. *Exp. Brain Res.* 38, 370–393. doi: 10.1080/0361073X.2012.699365

Mednick, S. A. (1962). The associative basis of the creative process. *Psychol. Rev.* 69, 220–232. doi: 10.1037/h0048850

Mirelman, A., Herman, T., Brozgol, M., Dorfman, M., Sprecher, E., Schweiger, A., et al. (2012). Executive function and falls in older adults: new findings from a five-year prospective study link fall risk to cognition. *PLoS ONE* 7:e40297. doi: 10.1371/journal.pone.0040297

Mozolic, J. L., Hugenschmidt, C. E., Peiffer, A. M., and Laurienti, P. J. (2012). "Multisensory integration and aging," in *The Neural Bases of Multisensory Processes*, eds M. M. Murray and M. T. Wallace (Boca Raton, FL: CRC Press), Available at: http://www.ncbi.nlm.nih.gov/books/NBK92841/

Mund, I., Bell, R., and Buchner, A. (2012). Aging and interference in story recall. *Exp. Aging Res.* 38, 20–41. doi: 10.1080/0361073X.2012.636724

Nagamatsu, L. S., Voss, M., Neider, M. B., Gaspar, J. G., Handy, T. C., Kramer, A. F., et al. (2011). Increased cognitive load leads to impaired mobility decisions in seniors at risk for falls. *Psychol. Aging* 26, 253–259. doi: 10.1037/a0022929

Neider, M. B., Gaspar, J. G., McCarley, J. S., Crowell, J. A., Kaczmarski, H., and Kramer, A. F. (2011). Walking and talking: dual-task effects on street crossing behavior in older adults. *Psychol. Aging* 26, 260–268. doi: 10.1037/a0021566

Park, D. C., Lodi-Smith, J., Drew, L., Haber, S., Hebrank, A., Bischof, G. N., et al. (2014). The impact of sustained engagement on cognitive function in older adults: the Synapse Project. *Psychol. Sci.* 25, 103–112. doi: 10.1177/0956797613499592

Parmentier, F. B., and Andrés, P. (2010). The involuntary capture of attention by sound: novelty and postnovelty distraction in young and older adults. *Exp. Psychol.* 57, 68–76. doi: 10.1027/1618-3169/a000009

Peiffer, A. M., Mozolic, J. L., Hugenschmidt, C. E., and Laurienti, P. J. (2007). Age-related multisensory enhancement in a simple audiovisual detection task. *Neuroreport* 18, 1077–1081. doi: 10.1097/WNR.0b013e3281e72ae7

Pick, D. F., and Proctor, R. W. (1999). "Age differences in the effects of irrelevant location information," in *Automation Technology and Human Performance*, eds M. Scerbo, and M. W. Mouloua (Mahwah, NJ: Erlbaum), 258–261.

Sommers, M. S., and Huff, L. M. (2003). The effects of age and dementia of the Alzheimer's type on phonological false memories. *Psychol. Aging* 18, 791–806. doi: 10.1037/0882-7974.18.4.791

Spieler, D. H., Balota, D. A., and Faust, M. E. (1996). Stroop performance in healthy younger and older adults and in individuals with dementia of the Alzheimer's type. *J. Exp. Psychol. Human* 22, 461–479. doi: 10.1037/0096-1523.22.2.461

Spreng, R. N., Stevents, W. D., Chamberlain, J. P., Gilmore, A. W., and Schacter, D. L. (2010). Default network activity, coupled with frontoparietal control network, supports goal-directed cognition. *Neuroimage* 53, 303–317. doi: 10.1016/j.neuroimage.2010.06.016

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *J. exp. psychol.* 18, 643–662. doi: 10.1037/h0054651

Thompson, K. R., Johnson, A. M., Emerson, J. L., Dawson, J. D., Boer, E. R., and Rizzo, M. (2012). Distracted driving in elderly and middle-aged drivers. *Accid. Anal. Prev.* 45, 711–717. doi: 10.1016/j.aap.2011.09.040

Tun, P. A., O'Kane, G., and Wingfield, A. (2002). Distraction by competing speech in young and older adult listeners. *Psychol. Aging* 17, 453–467. doi: 10.1037/0882-7974.17.3.453

Vincent, J. L., Kahn, I., Snyder, A. Z., Raichle, M. E., and Buckner, R. L. (2008). Evidence for a frontoparietal control system revealed by intrinsic functional connectivity. *J. Neurophysiol.* 100, 3328–3342. doi: 10.1152/jn.90355.2008

Wais, P. E., Martin, G. M., and Gazzaley, A. (2012). The impact of visual distraction on episodic retrieval in older adults. *Brain Res.* 1430, 78–85. doi: 10.1016/j.brainres.2011.10.048

West, R., and Alain, C. (2000). Age-related decline in inhibitory control contributes to the increased Stroop effect observed in older adults. *Psychophysiology* 37, 179–189. doi: 10.1111/1469-8986.3720179

Wright, P., Soroka, A. J., Belt, S., Pham, D. T., Dimov, S., DeRoure, D. C., et al. (2008). Modality preference and performance when seniors consult online information. *Gerontechnology* 7, 293–304. doi: 10.4017/gt.2008.07.03.004.00

Wurm, L. H., Labouvie-Vief, G., Aycock, J., Rebucal, K. A., and Koch, H. E. (2004). Performance in auditory and visual emotional Stroop tasks: a comparison of older and younger adults. *Psychol. Aging* 19, 523–535. doi: 10.1037/0882-7974.19.3.523

Yang, L., and Hasher, L. (2007). The enhanced effects of pictorial distraction in older adults. *J. Gerontol. B Psychol. Sci. Soc. Sci.* 62, 230–233. doi: 10.1093/geronb/62.4.P230

Young, K. and Regan, M. (2007). "Driver distraction: a review of the literature," in *Distracted Driving*, eds I. J. Faulks, M. Regan, M. Stevenson, J. Brown, A. Porter, and J. D. Irwin (Sydney, NSW: Australasian College of Road Safety), 379–405.

Zeef, E. J., Sonke, C. J., Kok, A., Buiten, M. M., and Kenemans, J. (1996). Perceptual factors affecting age-related differences in focused attention: performance and psychophysiological analyzes. *Psychophysiology* 33, 555–565. doi: 10.1111/j.1469-8986.1996.tb02432.x

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Failure to see money on a tree: inattentional blindness for objects that guided behavior

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How is it possible to drive home and have no awareness of the trip? We documented a new form of inattentional blindness in which people fail to become aware of obstacles that had guided their behavior. In our first study, we found that people talking on cell phones while walking waited longer to avoid an obstacle and were less likely to be aware that they had avoided an obstacle than other individual walkers. In our second study, cell phone talkers and texters were less likely to show awareness of money on a tree over the pathway they were traversing. Nonetheless, they managed to avoid walking into the money tree. Perceptual information may be processed in two distinct pathways – one guiding behavior and the other leading to awareness. We observed that people can appropriately use information to guide behavior without awareness.

Keywords: inattentional blindness, cell phone, attention, visual attention, perception-action dissociation, ventral and dorsal visual streams, two visual systems hypothesis

INTRODUCTION

How is it possible to safely drive home, yet have little awareness of the trip? This common experience occurs during driving and walking – people can arrive at their location with little awareness of the trip and no memory for objects passed along the way. In some cases, people may arrive at a typical target location but fail to stop at an intended location – you may find yourself at home having failed to stop at the grocery store on the way as you intended. In other words, people appear able to drive and walk without complete awareness of performing the navigation task.

There are two broad categories of possible explanations. One possible explanation is that people were aware of the road and obstacles during the drive, but immediately forgot those features. Alternatively, driving without awareness may represent a form of inattentional blindness, in which objects that pass through the focal point of vision do not enter awareness (Neisser and Becklen, 1975; Becklen and Cervone, 1983; Mack and Rock, 1998; Simons and Chabris, 1999; Simons, 2000). People may use visual information to guide the control of actions, but may not devote attention to objects. Without attention, people may fail to bind features into objects (Treisman and Gelade, 1980; Wolfe, 2007) and thus may fail to become aware of the things they pass when driving or walking. This second possible explanation would be consistent with the theoretical claim that visual information follows two pathways after low level visual processing (Goodale and Milner, 1992; Jeannerod and Jacob, 2005; Westwood and Goodale, 2011). One pathway is the dorsal pathway which uses visual information to guide action, enabling someone to grab an object or navigate around obstacles. The other pathway is the ventral pathway leading to object recognition and conscious awareness.

Inattentional blindness has been demonstrated in lab studies and naturalistic observations. In lab studies of inattentional blindness, people attend to one aspect of a complex event (counting basketball passes by one of two teams) and fail to notice an unusual event that occurs directly in front of their eyes, such as a gorilla or a woman carrying an umbrella (Neisser and Becklen, 1975; Becklen and Cervone, 1983; Mack and Rock, 1998; Simons and Chabris, 1999). Inattentional blindness also occurs in naturalistic settings caused by cell phone conversations during driving and walking (Strayer et al., 2003; Strayer and Drews, 2007; Hyman et al., 2010). In driving simulators, cell phone use leads to decreased recognition of objects that individuals drove past, even though they were just as likely to have looked at the objects (Strayer et al., 2003). People will fail to notice a unicycling clown when talking on a cell phone while walking (Hyman et al., 2010) and a fight when running and tracking another person (Chabris et al., 2011). Inattentional blindness occurs because divided attention in a complex environment decreases awareness of objects that are not the focus of attention. In each of these instances of inattentional blindness, the objects that people failed to notice were interesting and surprising, but were not directly related to the person's primary task.

Cell phone use not only disrupts awareness in a divided attention situation, but also impacts the control of behavior. People using a cell phone walk more slowly, weave, and change directions more often than people who are not using their cell phones (Hyman et al., 2010), display less safe behavior crossing a street (Neider et al., 2010; Schwebel et al., 2012; Nasar and Troyer, 2013) and experience difficulties using visual information to guide the control of walking through doorways (Lopresti-Goodman et al., 2012). In driving simulators, people using cell phones also display more difficulties controlling the car and responding to changes in the environment (Strayer et al., 2003, 2006; Rakauskas et al., 2004; Kubuse et al., 2006; Törnros and Bolling, 2006; Horrey and Simons, 2007; Drews et al., 2008; Bellinger et al., 2009). Clearly, cell phone use and divided attention disrupts both awareness of the world (the ventral pathway) and the control of behavior (the dorsal pathway).

Nonetheless, we suspect that divided attention may cause greater disruptions to awareness than control of behavior. Even without complete awareness of objects and the environmental layout, people may be able to use visual information to guide walking: people may move to avoid an object without recognizing what the object is. Several lines of evidence are consistent with this possibility.

One line of evidence consistent with a difference between awareness and behavior control comes from differences in perception of slopes and physical responses to slopes. Proffitt et al. (1995) have found that when people provide verbal estimates of the slope of a hill they tend to overestimate that slope. The size of the overestimating error is related to a variety of factors. People estimate the slope is steeper from the top than from the bottom, after a run, and when wearing a heavy backpack (Proffitt et al., 1995; Bhalla and Proffitt, 1999). Nonetheless when people use their hands to directly match the slope of the hill, they accurately create the correct slope. Proffitt (2013) argued that there is a dissociation between awareness and bodily control, a claim that has been questioned by other researchers (Durgin et al., 2009, 2012; Firestone, 2013).

Similar dissociations between awareness and action have been found with visual illusions. People visually perceive lines as different in length in the Müller-Lyer and circles as different in size in the Ebbinghaus illusion. Even when someone understands these illusions, that person will nonetheless see the lines and circles as different sizes. But in versions of the illusions that allow people to perform actions, they do not consistently display the illusions in their behaviors. For example, people see the illusory length difference in the Müller-Lyer illusion, but nonetheless point accurately and walk the correct distance when blindfolded (Wraga et al., 2000; Bruno et al., 2008). Similarly people will accurately set their grasp to allow them to pick up the center circle in the Ebbinghaus illusion (Aglioti et al., 1995; Lee and van Donkelaar, 2002; Culham et al., 2003) and other illusions (Bruno and Bernardis, 2002). Research on dissociations between action and awareness in visual illusions has been criticized because grasping is influenced by visual illusions in many situations (Franz et al., 2000; Franz, 2001; Bruno and Franz, 2009; Schenk et al., 2011). Thus Bruno and Franz (2009) argued that this line of research does not provide compelling evidence for the two visual systems hypothesis.

A more direct dissociation between action and awareness has recently been reported in a visual search task (Solman et al., 2012). Participants were presented with a pile of different shapes on a computer screen and were asked to move the objects to find a particular one. People frequently moved the target without recognizing it as the target. Thus they used visual information to direct behavior without necessarily becoming consciously aware of which object they moved. Usually participants became aware of the target object directly after missing it, but on a small number of trials they moved the target and did not return to the target for several moves.

Navigating in a complex real world environment may sometimes involve behavior being guided by objects that are not consciously recognized. For example, Yanko and Spalek (2014) found that people sometimes lose awareness while driving in a simulator. When probed, participants acknowledged occasions of mind-wandering; that is thinking about something other than the task of driving (see also He et al., 2011). Mind-wandering was associated with changes in driving including faster speed and slower responses to braking events. Individuals were more likely to drive without awareness on routes they had driven more frequently than on novel routes (Yanko and Spalek, 2013).

Becoming aware of an object is generally assumed to require focused attention. People must allocate some attention to bind a set of features to a location (Treisman and Gelade, 1980). Without attention, objects may nonetheless influence a person and guide behavior. If attention is more important for object recognition than directing behavior, then divided attention should be more disruptive of awareness than accurate navigation. Thus cell phone use while walking leads to inattentional blindness for interesting objects near an individual's path (Hyman et al., 2010). Other forms of distraction and divided attention also lead to inattentional blindness (Chabris et al., 2011) and to mistaken judgments of walking distance (Sargent et al., 2013). In spite of lapses of awareness in these studies, people successfully navigated through complex environments.

In the standard demonstrations of inattentional blindness, people fail to become aware of objects unrelated to their current task. We were interested in something more directly related to the phenomenon of driving and walking without awareness: can people experience inattentional blindness for obstacles that nonetheless guided behavior? We conducted two studies in which we placed obstacles directly in the pathway of walkers and checked if they avoided the obstacles and if they became aware of the obstacles. In essence, our argument is that visual information can be used to guide behaviors but that object recognition is processed separately and is dependent on attention (Treisman and Gelade, 1980; Goodale and Milner, 1992; Jeannerod and Jacob, 2005; Wolfe, 2007; Westwood and Goodale, 2011). Since cell phones may use attentional resources needed for object recognition, we looked at people walking with and without using cell phones. We predicted that even without using cell phones people would sometimes fail to become aware of the obstacles they avoid. In part this should occur because we placed our obstacles in a familiar pathway and this is a situation that should lead to mind-wandering and reduced awareness (Yanko and Spalek, 2013). We also predicted that individuals using their cell phones would be less likely to become aware of the obstacle because this should disrupt the use of focused attention needed for object recognition (Strayer et al., 2003; Hyman et al., 2010).

STUDY 1

METHODS

Participants

We observed individuals passing a signboard on a campus pathway. Observers rotated through three categories of individual walkers: 52 individuals with no electronics in use, 46 individuals listening to personal music players, and 43 individuals talking on a cell phone. If the observer went more than five minutes without being able to observe a person in the next category, the observer skipped to the following category. Observations were collected of 141 individuals (observers classified 75 as female, 62 as male, and 4 unsure; 124 were classified as college-aged, 11 as older, and 6 unsure).

Procedure

We placed a signboard on a pathway and observed when people moved to avoid the sign. The sign was placed at a point where people tend to stay near the edge of the path because the path curves to right approximately 30 feet beyond the placement. The signboard stated "Psychology Research in Progress". Discreet stakes were placed in the planting area beside the pathway at a distance of 5 and 10 feet before the signboard. Using the stakes, the observers noted at what point the walkers moved to avoid the signboard. The observers worked in pairs and were stationed across the pathway, near the entrance of a building. After each walker passed the signboard, the observers approached to ask a few questions. All walkers were approached 15 feet after passing the signboard such that their backs remained to the signboard. The observers first obtained permission to ask the walker a few questions. If the walker agreed, then the observer asked if they had passed any obstacles on the pathway. If the walker believed they had, then they were asked to identify the obstacle. If they did not volunteer the signboard as the obstacle, they were asked if they had passed a signboard and if they knew what was on the signboard (claiming anything about psychological research was counted as correct and no one said either psychology or research without the other term). Thus we collected both a behavioral measure (when they moved to avoid the signboard) and a perceptual awareness measure (awareness of what obstacle was avoided). Observers worked during normal class periods over a two week period when their schedules and weather permitted. We collected data until we obtained at least 40 observations in each condition (based on other similar studies in our lab we anticipated this would provide adequate power, Hyman et al., 2010).

RESULTS AND DISCUSSION

Cell phone use disrupted both control of behavior and awareness of the obstacle. In our results, we grouped individuals without electronics and those listening to music players. We planned throughout the study to combine these groups because we did not anticipate any differences based on previous research (Strayer and Johnston, 2001; Consiglio et al., 2003; Hyman et al., 2010; Neider et al., 2010; Walker et al., 2012). Preliminary analyses also indicated no differences between individuals with music players and individuals without any electronics.

People walking while talking on their cell phones were more likely to wait until they were within 5 feet of the signboard before changing their path to avoid the signboard than were individuals and people listening to music players [χ^2 (1, $N = 141$) = 5.58, $p = 0.018$]. Although most individuals moved early to avoid the signboard, 25.82% of the cell phone users waited until they were within five feet whereas only 10.20% of non-cell phone users waited until within five feet. This finding is consistent with other research findings showing that cell phone users display difficulty with behavioral control when walking (Consiglio et al., 2003; Nasar et al., 2008; Bellinger et al., 2009; Hyman et al., 2010) and when driving in a simulator (Strayer and Johnston, 2001; Strayer et al., 2003). **Table 1** presents the outcome measures grouped by cell phone users, music player users, and individuals without electronics. This provides additional information showing that cell phone users typically perform differently than other walkers.

When approached by the researchers, cell phone users were less likely to agree to respond to questions than were other walkers [χ^2 (1, $N = 141$) = 18.14, $p < 0.001$]. Only 62.79% of cell phone users agreed to respond whereas 91.84% of other walkers agree to participate. This may, of course, limit the accuracy of the awareness data for cell phone users. Most likely the cell phone users who refused to answer questions were those most engaged in their phone conversations. This would imply that they were less aware of their environment since cell phone conversations lead to inattentional blindness. In other words, while losing cell phone users was a problem, we may have lost individuals less aware of their surroundings, working against the pattern of the findings.

We then checked if the walkers were aware that they had walked past a signboard. Consistent with inattentional blindness, cell phone users were less likely to be aware that they had passed a signboard [χ^2 (1, $N = 117$) = 5.13, $p = 0.024$]. While 83.33% of individuals without electronics and individuals listening to music were aware that they had passed a signboard, only 62.96% of cell phone users were aware. When asked if they knew what was on the signboard, the difference between cell phone users (55.56%) and other walkers remained [77.78%; χ^2 (1, $N = 117$) = 5.16, $p = 0.023$].

We next investigated whether when people moved was related to the awareness of the obstacle. We did not have a clear set of predictions here. One possibility is that moving late (within 5 feet of the signboard) would reflect a lack of awareness of one's surroundings. We might expect people who moved late to display less awareness; that is more inattentional blindness. On the other hand, people who moved late may have suddenly become aware of the signboard and changed their walking direction in response to this last minute awareness. Thus late movers may have been more aware than early movers. Overall people who waited to move were less likely to be aware of the signboard [χ^2 (1, $N = 117$) = 4.65, $p = 0.031$]. For people who moved early, 82.00% were aware of the signboard but only 58.82% of people who moved within 5 feet were aware of the signboard.

Table 1 | Measures of behavior and awareness based on cell phone use in Study 1: the signboard.

	Walking condition		
	Cell phone	**Music player**	**No electronics**
Moved within 5 feet	25.8% (11/43)	10.9% (5/46)	9.6% (5/52)
Answered questions	62.8% (27/43)	95.7% (44/46)	88.5% (46/52)
Saw signboard	63.0% (17/27)	77.3% (34/44)	89.1% (41/46)
Knew content	55.6% (15/27)	72.7% (32/44)	82.6% (38/46)

As we have already noted, when people moved was related to cell phone use. Therefore we conducted this analysis separately for cell phone users and other individuals. For cell phone users, moving early or late was unrelated to awareness of the signboard [χ^2 (1, $N = 27$) = 0.001, $p = 0.974$]. No matter when they moved, only 63% of cell phone users were aware of the signboard. For non-cell phone walkers, people who moved within 5 feet (55.56%) were less aware of the signboard than people who moved before 5 feet [86.42%; χ^2 (1, $N = 90$) = 5.56, $p = 0.018$].

Both control of walking and awareness of obstacles were influenced by cell phone use. Cell phone users moved to avoid an obstacle later and were less aware of the obstacle a few moments later than were other walkers. Importantly, people did not walk into the signboard. But for many individuals avoiding the obstacle did not lead to awareness of the obstacle. This is a real world demonstration of walking without awareness. The observation that people who moved to avoid the obstacle at the last moment were actually *less* likely to be aware of the object is important for this phenomenon. To some extent, we might have anticipated these individuals would become suddenly aware as they noticed and responded within 5 feet. Instead the visual information was sufficient to guide behavior without leading to conscious awareness. This is possibly a demonstration of a dissociation of behavior control and awareness. Such a dissociation is consistent with the claim that there are two pathways for visual information leading to behavior control and awareness (Goodale and Milner, 1992; Jeannerod and Jacob, 2005; Westwood and Goodale, 2011). This finding is also consistent with other instances in which awareness and body responses are inconsistent and appear somewhat dissociated (Aglioti et al., 1995; Wraga et al., 2000; Bruno and Bernardis, 2002; Proffitt, 2006; Bruno et al., 2008; Solman et al., 2012). Nonetheless, it is possible that participants were aware of the signboard but quickly forgot the object as they moved past the object. This interpretation would be consistent with criticisms of the two visual systems hypothesis (e.g., Bruno and Franz, 2009). For this reason, in our second study we used an unusual stimulus that we expected would result in distinct behaviors if walkers became aware of the stimulus – money on a tree.

STUDY 2

This study was inspired by "The Money Tree," a YouTube video in which Rosenthal (2010) placed 100 one-dollar bills on a tree. Although she was interested in watching the excited responses as people discovered the money, she observed that people generally failed to become aware of the money, even after avoiding the tree while walking and often after looking directly at the tree. With her permission, we examined her original 1 h recording from which the YouTube video was edited. Consistent with her claim, we found that few people became aware of the money. We judged awareness as stopping to examine or take the money. We recreated the money tree as an observational study.

METHODS

Participants

On several narrow pathways, we observed people as they passed money hanging on a branch over the path. Observations were collected of each individual who passed the money tree. If someone else was stopped to examine the money as an individual went by, we did not collect observations of the additional person since social interaction added an additional uncontrolled aspect to the situation. We observed 396 individuals (observers classified 193 as female and 203 as male; 375 were classified as college-aged and 21 as older). Most individuals were not using any electronic devices (268 individuals), 65 were using music players, 33 were talking on their cell phones, and 30 were texting.

Procedure

Three-dollar bills were clipped onto a branch of a deciduous tree beside a narrow path. We used paths between a set of dorms and the academic center of campus. The branch of the tree with the money was bent so that it hung over the path at head height (see **Figure 1** for a photograph of a research assistant walking past the money tree). Since the branch was positioned to extend down over the path, all individuals had to move their heads in order to not walk into the branch. Observers were positioned in pairs about 15 feet beyond the money tree in apparent conversation. Observers

FIGURE 1 | A research assistant walking past the money tree while texting.

collected data over a two-week period as weather and schedules permitted. Observations were collected until at least 30 people were observed in each category.

Because inattentional blindness can result in a failure to become aware of objects that pass directly through the focal point of vision, we depended on behavioral indexes of awareness. We counted individuals as displaying awareness of the money if they stopped to examine the money or if they took the money. Each dollar bill had a message taped to it noting that this was part of a psychology research project. Thus some people examined but did not take the money.

RESULTS AND DISCUSSION

As with Study 1, we planned to combine walkers without electronics with walkers with music players because previous research has found no differences between these conditions. We first compared and found no difference between cell phone talkers and texters. Thus we collapsed across these conditions. Individuals using their cell phones to talk or text were less likely to display clear evidence of awareness of the money (6.35%; 4 of 63) than those with no electronics or with music players (19.82%; 66 of 333). Thus cell phone use disrupted awareness of objects that people avoided while walking [χ^2 (1, $N = 396$) = 6.61, $p = 0.010$]. Although people rarely displayed overt awareness of the money, only 12 people (3.0%) walked into the branch with the money. Given so few observations, it was impossible to discern any difference based on walking condition for walking into the tree. We did not, however, observe any individual who walked into the tree stopping to take the money. In this fashion we observed that people can walk past potentially interesting objects and fail to display overt awareness of the objects. Most individuals failed to become aware of money on a tree.

We combined people talking and texting with a cell phone because we found no difference between these conditions – any use of a cell phone disrupted awareness of the money. From a working memory perspective (e.g., Baddeley and Hitch, 1974), texting should have been more disruptive because both texting and recognizing objects depend on the visual-spatial sketchpad aspect of working memory. We may have failed to find such an effect because of floor effects – almost no one with a cell phone displayed awareness of the money. Another possible explanation is that recognizing an object depends on executive control and any cell phone use also depends on executive control. At this point we cannot be sure if there is no difference between texting and talking or if we simply were unable to observe the difference in this study.

DISCUSSION

In two studies we observed that people can avoid obstacles in the walking path but nonetheless display little immediate awareness for what the object is and no memory for the object within a few moments of passing. Cell phone users were more likely to display this lack of awareness indicating the importance of attention for becoming aware of and recognizing objects. Of course many people listening to music and individuals who were not using any electronic devices also failed to remember passing a signboard and did not display awareness of money hanging on a tree. Failure to become aware of one's surroundings in these instances may represent an instance of mind-wandering while walking. The people may have become focused on their own thoughts and been less aware of their surroundings (He et al., 2011; Yanko and Spalek, 2013, 2014).

These naturalistic observations may be demonstrations of how people can drive home and seemingly have little awareness while driving and no memory for the trip after arriving home. People can use information about an object to guide behavior without becoming aware of what the object is – a clear dissociation between the guidance of behavior and awareness. These studies provide the evidence that people can experience inattentional blindness for objects that guided behavior. This is an important extension of inattentional blindness studies, since both traditional lab studies (Neisser and Becklen, 1975; Becklen and Cervone, 1983; Mack and Rock, 1998; Simons and Chabris, 1999) and naturalistic studies (Hyman et al., 2010; Chabris et al., 2011) have only demonstrated awareness failures for objects unrelated to the ongoing task. In another similar demonstration, Solman et al. (2012) recently found that people can move an object during a visual search task and not recognize that the object moved is the one for which they were searching.

One possible explanation of these findings is that perception may be processed in two somewhat independent pathways: the ventral pathway leading to object recognition and the dorsal pathway guiding behavior (Goodale and Milner, 1992; Jeannerod and Jacob, 2005; Westwood and Goodale, 2011). To the extent that the two pathways are somewhat independent, there should be observable dissociations between awareness and the control of behavior. Several lines of research have found dissociations that are consistent with the two visual pathways hypothesis. People differ in their perception of and behavior responses to the slopes of hills (Proffitt et al., 1995; Bhalla and Proffitt, 1999; Proffitt, 2006). In addition, even when people continue to be aware of visual illusions, the control of their walking and grasping indicates accurate control to match the real rather than perceived size of objects (Aglioti et al., 1995; Wraga et al., 2000; Bruno and Bernardis, 2002; Bruno et al., 2008). Our studies provide naturalistic observations of dissociations between awareness and the guidance of behavior that are consistent with the two visual pathways hypothesis. Particularly interesting for the two pathways argument is that even when people moved to avoid the signboard at the last moment, this did not lead to an increased awareness of the signboard.

The two visual systems hypothesis remains controversial. Bruno and Franz (2009) suggested several possible versions of the hypothesis varying in terms of the extent to which the systems are independent. Our data do not unequivocally support any particular two pathway perspective. Instead our findings demonstrated that people can avoid objects without complete awareness (since they failed to respond to the money) and without awareness a few moments later (since they were unaware they had avoided a signboard). We suspect that attention is more important for object recognition and awareness than for the control of behavior. To recognize and become aware of objects, people must use attention to bind features to locations creating object files (Treisman and Gelade, 1980; Wolfe, 2007). People may have been aware that there was an object, but without attention may not have become aware of what the object was.

Although there is evidence that the dorsal and ventral visual pathways lead to dissociations between awareness and the guidance of movement, clearly the two systems interact in meaningful ways (Bruno and Franz, 2009; Schenk and McIntosh, 2010). We found that while awareness was particularly disrupted by cell phone divided attention, divided attention also impacted the control of behavior. People talking on their cell phones moved later to avoid the obstacle in their pathway than other walkers. This disruption of the guidance of behavior is consistent with other findings concerning the impact of cell phones on both walking behavior (Hyman et al., 2010; Neider et al., 2010; Lopresti-Goodman et al., 2012; Schwebel et al., 2012; Nasar and Troyer, 2013) and driving (Strayer et al., 2003, 2006; Rakauskas et al., 2004; Kubuse et al., 2006; Törnros and Bolling, 2006; Horrey and Simons, 2007; Drews et al., 2008; Bellinger et al., 2009). People may be able to walk and drive with little conscious awareness, but they are not nearly as safe and competent as when awareness is also involved. Divided attention makes people slower to respond to objects. This would suggest that awareness may be necessary to plan for movements further in advance (Bruno and Franz, 2009). Additionally, object recognition is important for making the appropriate response. For example, a driver needs to respond differently to a large truck, a car, a bicyclist, and a pedestrian. Thus awareness appears to be important for guiding behavior – we should not rely on the perceptual auto-pilot to get us safely home. These findings are important since people continue to report wide acceptance of cell phone use during driving and many other activities (Forgays et al., 2014). Reducing cognitive distractions, such as cell phone use, should lead to both more awareness of one's surroundings and better control of behavior.

We observed inattentional blindness for avoided obstacles in both studies. We also observed that people waited longer to respond to the signboard, showing that divided attention disrupts the control of behavior. While the results of these naturalistic observations are consistent with the two visual pathways hypothesis, they do not provide unimpeachable evidence. People on cell phones may be distracted, but they nonetheless avoided both the signboard and the money tree. Divided attention is known to disrupt memory. Thus cell phone use may have disrupted holding the awareness of the obstacles in working memory. This possibility is certainly consistent with the findings of our studies as well. Increased forgetting from working memory is also consistent with the general phenomenon of driving home and realizing one has no awareness of the trip. Conceivably one could have been aware of the drive and the obstacles during the drive. But if working memory was occupied with other concerns, such as a cell phone call or mind-wandering, then the information might have been quickly lost from memory.

Our observations provide empirical examples of people walking, avoiding obstacles, and displaying little awareness of the obstacles. People can pass a signboard and fail to be aware of having done so within a few moments. People can walk past a tree, move to avoid a branch, and fail to become aware of money hanging directly in front of their faces. Apparently people may be able to guide behavior without awareness. Inattentional blindness for objects one avoids is a form of mindless wandering that allows us to walk and drive without awareness of avoided obstacles.

REFERENCES

Aglioti, S., DeSouza, J. F. X., and Goodale, M. A. (1995). Size-contrast illusions deceive the eye but not the hand. *Curr. Biol.* 5, 679–685. doi: 10.1016/S0960-9822(95)00133-3

Baddeley, A. D., and Hitch, G. J. (1974). "Working memory," in *Recent Advances in Learning and Memory,* ed. G. Bower (New York, NY: Academic Press), 47–90.

Becklen, R., and Cervone, D. (1983). Selective looking and the noticing of unexpected events. *Mem. Cognit.* 11, 601–608. doi: 10.3758/BF03198284

Bellinger, D. B., Budde, B. M., Machida, M., Richardson, G. B., and Berg, W. P. (2009). The effect of cellular telephone conversation and music listening on response time in braking. *Transp. Res. Part F* 12, 441–451. doi: 10.1016/j.trf.2009.08.007

Bhalla, M., and Proffitt, D. R. (1999). Visual-motor recalibration in geographical slant perception. *J. Exp. Psychol. Hum. Percept. Perform.* 25, 1076–1096. doi: 10.1037/0096-1523.25.4.1076

Bruno, N., and Bernardis, P. (2002). Dissociating perception and action in Kanizsa's compression illusion. *Psychon. Bull. Rev.* 9, 723–730. doi: 10.3758/BF03196327

Bruno, N., Bernardis, P., and Gentilucci, M. (2008). Visually guided pointing, the Müller-Lyer illusion, and the functional interpretation of the dorsal-ventral split: conclusions from 33 independent studies. *Neurosci. Biobehav. Rev.* 32, 423–437. doi: 10.1016/j.neubiorev.2007.08.006

Bruno, N., and Franz, V. H. (2009). When is grasping affected by the Müller-Lyer illusion? A quantitative review. *Neuropsychologia* 47, 1421–1433. doi: 10.1016/j.neuropsychologia.2008.10.031

Chabris, C. F., Weinberger, A., Fontaine, M., and Simons, D. J. (2011). You do not talk about Fight Club if you do not notice Fight Club: inattentional blindness for a simulated real-world assault. *Iperception* 2, 150–153. doi: 10.1068/i0436

Consiglio, W., Driscoll, P., Witte, M., and Berg, W. P. (2003). Effect of cellular telephone conversations and other potential interference on reaction time in a braking response. *Accid. Anal. Prev.* 35, 495–500. doi: 10.1016/S0001-4575(02)00027-1

Culham, J. C., Danckert, S. L., DeSouza, J. F. X., Gati, J. S., Menon, R. S., and Goodale, M. A. (2003). Visually guided grasping produces fMRI activation in dorsal but not ventral stream brain areas. *Exp. Brain Res.* 153, 180–189. doi: 10.1007/s00221-003-1591-5

Drews, F. A., Pasupathi, M., and Strayer, D. L. (2008). Passenger and cell phone conversations in simulated driving. *J. Exp. Psychol. Appl.* 14, 392–400. doi: 10.1037/a0013119

Durgin, F. H., Baird, J. A., Greenburg, M., Russell, R., Shaughnessy, K., and Waymouth, S. (2009). Who is being deceived? The experimental demands of wearing a backpack. *Psychon. Bull. Rev.* 16, 964–969. doi: 10.3758/PBR.16.5.964

Durgin, F. H., Klein, B., Spiegel, A., Strawser, C. J., and Williams, M. (2012). The social psychology of perception experiments: hills, backpacks, clucose, and the problem of generalizability. *J. Exp. Psychol. Hum. Percept. Perform.* 38, 1582–1595. doi: 10.1037/a0027805

Firestone, C. (2013). How "Paternalistic" is spatial perception? Why wearing a heavy backpack doesn't – and couldn't – make hills look steeper. *Perspect. Psychol. Sci.* 8, 455–473. doi: 10.1177/1745691613489835

Forgays, D. K., Hyman, I. E., Jr., and Schreiber, J. (2014). Texting everywhere for everything: gender and age differences in cell phone etiquette and use. *Comput. Human Behav.* 31, 314–321. doi: 10.1016/j.chb.2013.10.053

Franz, V. H. (2001). Action does not resist visual illusions. *Trends Cogn. Sci.* 5, 457–459. doi: 10.1016/S1364-6613(00)01772-1

Franz, V. H., Gegenfurtner, K. R., Bülthoff, H. H., and Fahle, M. (2000). Grasping visual illusions: no evidence for a dissociation between perception and action. *Psychol. Sci.* 11, 20–25. doi: 10.1111/1467-9280.00209

Goodale, M. A., and Milner, A. D. (1992). Separate visual pathways for perception and action. *Trends Neurosci.* 15, 20–25. doi: 10.1016/0166-2236(92)90344-8

He, J., Becic, E., Lee, Y.-C., and McCarley, J. S. (2011). Mind wandering behind the wheel: performance and oculomotor correlates. *Hum. Factors* 53, 13–21. doi: 10.1177/0018720810391530

Horrey, W. J., and Simons, D. J. (2007). Examining cognitive interference and adaptive safety behaviours in tactical vehicle control. *Ergonomics* 50, 1340–1350. doi: 10.1080/00140130701318889

Hyman, I. E., Jr., Boss, S. M., Wise, B. M., McKenzie, K. E., and Caggiano, J. M. (2010). Did you see the unicycling clown? Inattentional blindness while walking and talking on a cell phone. *Appl. Cogn. Psychol.* 24, 596–607. doi: 10.1002/acp.1638

Jeannerod, M., and Jacob, P. (2005). Visual cognition: a new look at the two-visual systems model. *Neuropsychologia* 43, 301–312. doi: 10.1016/j.neuropsychologia.2004.11.016

Kubuse, T. T., Bock, K., Dell, G. S., Garnsey, S. M., Kramer, A. F., and Mayhugh, J. (2006). The effects of speech production and speech comprehension on simulated driving performance. *Appl. Cogn. Psychol.* 20, 43–63. doi: 10.1002/acp.1164

Lee, J.-H., and van Donkelaar, P. (2002). Dorsal and ventral visual stream contributions to perception-action interactions during pointing. *Exp. Brain Res.* 143, 440–446. doi: 10.1007/s00221-002-1011-2

Lopresti-Goodman, S. M., Rivera, A., and Dressel, C. (2012). Practicing safe text: the impact of texting on walking behavior. *Appl. Cogn. Psychol.* 26, 644–648. doi: 10.1002/acp.2846

Mack, A., and Rock, I. (1998). *Inattentional Blindness.* Cambridge, MA: MIT Press.

Nasar, J., Hecht, P., and Wener, R. (2008). Mobile telephones, distracted attention, and pedestrian safety. *Accid. Anal. Prev.* 40, 69–75. doi: 10.1016/j.aap.2007.04.005

Nasar, J. L., and Troyer, D. (2013). Pedestrian injuries due to mobile phone use in public places. *Accid. Anal. Prev.* 57, 91–95. doi: 10.1016/j.aap.2013.03.021

Neider, M. B., McCarley, J. S., Crowell, J. A., Kaczmarski, H., and Kramer, A. F. (2010). Pedestrians, vehicles, and cell phones. *Accid. Anal. Prev.* 42, 589–594. doi: 10.1016/j.aap.2009.10.004

Neisser, U., and Becklen, R. (1975). Selective looking: attending to visually specified events. *Cognit. Psychol.* 7, 480–494. doi: 10.1016/0010-0285(75)90019-5

Proffitt, D. R. (2006). Embodied perception and the economy of action. *Perspect. Psychol. Sci.* 1, 110–122. doi: 10.1111/j.1745-6916.2006.00008.x

Proffitt, D. R. (2013). An embodied approach to perception: by what units are visual perceptions scaled? *Perspect. Psychol. Sci.* 8, 474–483. doi: 10.1177/1745691613489837

Proffitt, D. R., Bhalla, M., Gossweiler, R., and Midget, J. (1995). Perceiving geographical slant. *Psychon. Bull. Rev.* 2, 409–428. doi: 10.3758/BF03210980

Rakauskas, M. E., Gugerty, L. J., and Ward, N. J. (2004). Effects of naturalistic cell phone conversations on driving performance. *J. Safety Res.* 35, 453–464. doi: 10.1016/j.jsr.2004.06.003

Rosenthal, A. K. (2010). *Amy KR Presents* "*The Money Tree*" *(Video File),* September 2, Available at: http://www.youtube.com/watch?v=ZsN8FUV9nS4

Sargent, J. Q., Zacks, J. M., Philbeck, J. W., and Flores, S. (2013). Distraction shrinks space. *Mem. Cognit.* 41, 769–780. doi: 10.3758/s13421-013-0303-z

Schenk, T., and McIntosh, R. D. (2010). Do we have independent visual streams for perception and action? *Cogn. Neurosci.* 1, 52–62. doi: 10.1080/17588920903388950

Schenk, T., Franz, V. H., and Bruno, N. (2011). Vision-for-perception and vision-for-action: which model is compatible with the available psychophysical and neuropsychological data? *Vision Res.* 51, 812–818. doi: 10.1016/j.visres.2011.02.003

Schwebel, D. C., Stavrinos, D., Byington, K. W., Davis, T., O'Neal, E. E., and de Jong, D. (2012). Distraction and pedestrian safety: how talking on the phone, texting, and listening to music impact crossing the street. *Accid. Anal. Prev.* 45, 266–271. doi: 10.1016/j.aap.2011.07.011

Simons, D. J. (2000). Attentional capture and inattentional blindness. *Trends Cogn. Sci.* 4, 147–155. doi: 10.1016/S1364-6613(00)01455-8

Simons, D. J., and Chabris, C. F. (1999). Gorillas in our midst: sustained inattentional blindness for dynamic events. *Perception* 28, 1059–1074. doi: 10.1068/p2952

Solman, G. J. F., Cheyne, J. A., and Smilek, D. (2012). Found and missed: failing to recognize a search target despite moving it. *Cognition* 123, 100–118. doi: 10.1016/j.cognition.2011.12.006

Strayer, D. L., and Drews, F. A. (2007). Cell-phone-induced driver distraction. *Curr. Dir. Psychol. Sci.* 16, 128–131. doi: 10.1111/j.1467-8721.2007.00489.x

Strayer, D. L., Drews, F. A., and Crouch, D. J. (2006). A comparison of the cell phone driver and the drunk driver. *Hum. Factors* 48, 381–391. doi: 10.1518/001872006777724471

Strayer, D. L., Drews, F. A., and Johnston, W. A. (2003). Cell phone-induced failures of visual attention during simulated driving. *J. Exp. Psychol. Appl.* 9, 23–32. doi: 10.1037/1076-898X.9.1.23

Strayer, D. L., and Johnston, W. A. (2001). Driven to distraction: dual-task studies of simulated driving and conversing on a cellular telephone. *Psychol. Sci.* 12, 462–466. doi: 10.1111/1467-9280.00386

Törnros, J., and Bolling, A. (2006). Mobile phone use: effects of Conversation on mental workload and driving speed in rural and urban environments. *Transp. Res. Part F* 9, 298–306. doi: 10.1016/j.trf.2006.01.008

Treisman, A. M., and Gelade, G. (1980). A feature-integration theory of attention. *Cognit. Psychol.* 12, 97–136. doi: 10.1016/0010-0285(80)90005-5

Walker, E. J., Lanthier, S. N., Risko, E. F., and Kingstone, A. (2012). The effects of personal music devices on pedestrian behavior. *Saf. Sci.* 50, 123–128. doi: 10.1016/j.ssci.2011.07.011

Westwood, D. A., and Goodale, M. A. (2011). Converging evidence for diverging pathways: neuropsychology and psychophysics tell the same story. *Vision Res.* 51, 804–811. doi: 10.1016/j.visres.2010.10.014

Wolfe, J. M. (2007). "Guided search 4.0: current progress with a model of visual search," in *Integrated Models of Cognitive Systems,* ed. W. Gray (New York: Oxford University Press), 99–119.

Wraga, M., Creem, S. H., and Proffitt, D. R. (2000). Perception-action dissociations of a walkable Müller-Lyer configuration. *Psychol. Sci.* 11, 239–243. doi: 10.1111/1467-9280.00248

Yanko, M. R., and Spalek, T. M. (2013). Route familiarity breeds inattention: a driving simulator study. *Accid. Anal. Prev.* 57, 80–86. doi: 10.1016/j.aap.2013.04.003

Yanko, M. R., and Spalek, T. M. (2014). Driving with the wandering mind: the effect that mind-wandering has on driving performance. *Hum. Factors.* 56, 260–269. doi: 10.1177/0018720813495280

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Eye-closure increases children's memory accuracy for visual material

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Research shows that closing the eyes during retrieval can help both adults and children to remember more about witnessed events. In this study, we investigated whether the eye-closure effect in children is explained by general cognitive load, modality-specific interference, or a combination. 120 children (60 female) aged between 8 and 11 years viewed a 5-min clip depicting a theft and were questioned about the event. During the cued-recall interview, children either viewed a blank screen (blank-screen condition), kept their eyes closed (eye-closure condition), were exposed to visual stimuli (visual-distraction condition), or were exposed to auditory stimuli (auditory-distraction condition). Children in the blank-screen and eye-closure conditions provided significantly more correct and fewer incorrect responses about visual details than children in the visual- and auditory-distraction conditions. No advantage was found for auditory details. These results support neither a pure cognitive-load explanation (in which the effect is expected to be observed for recall of both visual and auditory details), nor a pure modality-specific account (in which recall of visual details should only be disrupted by visual distractions). Practical implications of the findings are discussed.

Keywords: children, eye-closure, memory retrieval, investigative interviewing, cognitive load, modality-specific interference

INTRODUCTION

One critical point in criminal investigation, especially in the early stages, is gathering evidence through questioning the witness/victim. When interviewing a child, this stage becomes even more crucial due to the cognitive and psychological factors affecting performance of this particular group of witnesses. In fact, children tend to report less information compared to adults, despite being generally accurate (see Goodman and Melinder, 2007, for a review), and may experience difficulties in focusing their attention for prolonged times. They are also prone to be influenced by situational factors such as the characteristics of the interviewer (e.g., age and status) and of the interview itself (e.g., social cues and types of requests; see Krähenbühl and Blades, 2006; Quas et al., 2007). In order to overcome these issues, researchers have developed or adapted a number of interview protocols with the purpose to help professionals gather accurate information from a child witness (e.g., Cognitive Interview: Fisher and Geiselman, 1992; Stepwise Interview: Yuille et al., 1993). These protocols generally help the child to remember more accurately, but there is also evidence of a small increase on the number of errors (see, for example, Memon et al., 1997 for a meta analysis on the Cognitive Interview).

In addition, although experts in many countries are trained in one or more of such protocols, surveys with police officers and other professionals, such as social workers, show that in many cases they incorrectly or only partially make use of such techniques (Kebbell and Wagstaff, 1999; Kebbell et al., 1999; Clarke and Milne, 2001). This is frequently due to a lack of appropriate training or time constraints when conducting the interview. Therefore, in recent years researchers have focused on investigating simpler strategies to increase witnesses' accuracy that are easier to implement in practice. Dando et al. (2009), for instance, proposed a modified Cognitive Interview procedure based on the PEACE model, namely the Modified Peace Cognitive Interview Procedure (MPCI), in which mental reinstatement of context is replaced by a *sketch mental reinstatement of context* in which participants are asked to draw a sketch of the event to generate their own retrieval cues. In its shortened version, including a sketch free recall and a final free recall in lieu of a change of temporal order, this procedure proved to be effective and less time-consuming than the standard MPCI. Another valuable interviewing tool recently developed by Wagstaff and Wheatcroft (2010, Unpublished document; as cited in Wagstaff et al., 2011a,b) is the Liverpool Interview Protocol—a brief procedure for use in the field that combines the Focused Meditation, eye-closure, and context reinstatement elements.

An even simpler strategy is instructing witnesses to close their eyes during recall. When one has to focus on a task it is quite common for both children and adults to spontaneously close the eyes or look away in order to reduce interference from external sources and perform better (Doherty-Sneddon et al., 2002; Doherty-Sneddon and Phelps, 2005; Phelps et al., 2006; Markson and Paterson, 2009; Wais et al., 2010). In recent studies, instructing adults or children to close the eyes when recalling an event has been shown to increase the number of correct details reported, while at the same time decreasing the number of errors. Studies conducted with adults showed that eye-closure improves performance on mathematical and general-knowledge tests (Glenberg et al., 1998). Furthermore, eye-closure increases memory performance for visual details in a witnessed event (see Vredeveldt et al., 2012, 2013) and in some studies also for auditory details (see Perfect et al., 2008; Vredeveldt and Penrod, 2012). Studies conducted with children found that children instructed to avert their gaze (Phelps et al., 2006) or close their eyes (Mastroberardino et al., 2012; Natali et al., 2012) also perform better on arithmetic and verbal-reasoning tasks, and remember more correct information about witnessed events. Additionally, Natali et al. found that eye-closure increased children's memory accuracy for both visual and auditory details.

Based on their findings, Perfect et al. (2008) concluded that eye-closure has a *general* effect: it reduces cognitive load, resulting in benefits for recall of both visual and auditory details (see also Perfect et al., 2011, 2012). However, other findings that eye-closure predominantly benefits recall of visual details (Vredeveldt et al., 2012, 2013) point to a modality-specific effect: eye-closure reduces visual distractions in the environment, which specifically enhances performance on tasks that are visual in nature, such as recall of visual details. Vredeveldt et al. (2011) conducted a direct test of the general and modality-specific accounts of the eye-closure effect, respectively, by varying the nature of distractions during the interview. They found evidence for both general and modality-specific accounts. Thus, memory performance was better when distraction during the interview was minimal (most likely due to a reduction in general cognitive load). In addition, recall of visual material was most disrupted by exposure to visual distractions, whereas recall of auditory material was most disrupted by exposure to auditory distractions (i.e., a modality-specific interference effect). Finally, they found no significant difference between participants who closed their eyes and participants who looked at a blank screen during the interview, suggesting that reducing visual distractions in the environment is as effective as eye-closure.

The study conducted by Vredeveldt et al. (2011) suggests that, for adults, eye-closure reduces general cognitive load as well as modality-specific interference. However, it is not clear whether eye-closure has the same effects on children's performance. For example, two recent studies on the role of repeated recall and delay in the eye-closure effect, one conducted with adults (Vredeveldt et al., 2013) and one conducted with children (Natali et al., 2012), came to slightly different conclusions. In both studies, eye-closure during an interview taking place approximately 1 week after the witnessed event significantly improved recall performance. However, Natali et al. also found that children benefited from eye-closure during an interview taking place immediately after the event, whereas Vredeveldt et al. did not observe such benefits for adult participants. Thus, it is possible that eye-closure differentially affects memory in children and adults. A possible explanation for any differences between children and adults may relate to developmental differences. It is possible that the task of recalling information from a video seen immediately prior to the interview was not too cognitively demanding for adults. This could explain why eye-closure did not have an effect, since eye-closure is generally found to be most beneficial for cognitive tasks that are at least moderately difficult (cf. Glenberg et al., 1998). For children, on the other hand, even recall immediately after viewing an event may be a relatively difficult task, due to age differences in cognitive control capacity of attention shifting (see Enns, 1990, for a review). Thus, eye-closure may have helped children to allocate their attentional resources more effectively, by allowing them to disengage from irrelevant information in the environment and focusing their attention on the recall task.

In this study, we aim to investigate the relative influences of general and modality-specific components in the eye-closure effect in children. Based on previous research with adults (Vredeveldt et al., 2011), we hypothesized that (a) children exposed to minimal distraction during the memory task would provide more correct responses and fewer incorrect responses than children exposed to visual or auditory distractions, and (b) recall of visual material would be most disrupted by visual distractions, whereas recall of auditory material would be most disrupted by auditory distractions. However, due to differences related to development of cognitive control of voluntary attention (i.e., attention shifting, see Enns, 1990), we could not be certain that the same pattern would emerge in children.

METHODS

PARTICIPANTS

One hundred and twenty children (60 female) aged between 8 and 11 years ($M = 8.99$; $SD = 0.87$) voluntarily participated in this study. Children were recruited from schools in Rome and had no familiarity with spoken or written Hebrew. This study was approved by the ethical committee of the Sapienza University of Rome and parents and teachers gave their informed consent before participation.

MATERIALS

All experimental materials were in Italian. A 5-min clip created for this experiment was used as study material (see Supplementary Material for a detailed description). The clip shows a series of events taking place in a private residence: a girl making a phone call, a parcel being delivered, the delivery man stealing a 50 Euros bill from a wallet, and a group of friends meeting up for a chat. In order to provide some memorable data to our participants, six clearly discriminable people appeared in the video, different scenes took place in clearly identifiable rooms in an apartment (i.e., kitchen, living room etc.), and names of the actors were clearly spoken.

DESIGN AND PROCEDURE

This study employed a 4 (Interview Condition: blank screen, eyes closed, visual distraction, auditory distraction) × 2 (Modality of Encoded Information: visual, auditory) mixed design. All participants were tested individually in a small room during school hours. The experimenter welcomed the children and told them that they were going to see a short movie and that they had to answer some questions about it later. The clip was then presented on a 14.5′ television screen. Following this, participants were randomly assigned to one of the four interview conditions and presented with an 18-item open-ended questionnaire (9 questions on visual and 9 questions on auditory details, see Supplementary Material). They were instructed to respond according to what they remembered and to avoid guessing by saying "don't know." Participants in the blank screen condition (control group), were instructed to look at the blank screen throughout the interview, while participants in the eye closure condition were asked to keep their eyes closed. The visual- and auditory-distraction stimuli were identical to those used by Vredeveldt et al. (2011) with adult participants. Children in the visual distraction condition were instructed to look at the screen where Hebrew words (in Hebrew script) were presented in random locations (one per second), while participants in the auditory distraction condition looked at the blank screen while they heard Hebrew words being spoken (one per second). If, at any point during the interview, participants failed to follow the instruction (e.g., they looked away from the screen or opened their eyes) the interviewer reminded them what they were instructed to do at the beginning of the questioning phase. All children completed the experiment and after the questioning phase were fully debriefed and thanked for their participation.

RESULTS

A preliminary analysis showed no significant influence of age on participants' performance. The means and standard deviations for correct responses, incorrect responses, confabulated responses, and "don't know" (DK) responses are shown in **Table 1**. For correct and incorrect responses, we conducted 4 (Interview Condition: blank screen, eyes closed, visual distraction, auditory distraction) × 2 (Modality of Encoded Information: visual, auditory) mixed analyses of variance (ANOVA) with repeated measures on the second factor. For confabulated and DK responses, we conducted Kruskal-Wallis tests, because the data were positively skewed and leptokurtic, and transformations did not correct this.

CORRECT RESPONSES

An ANOVA on proportion correct revealed a significant effect of modality of encoded information, $F_{(1, 116)} = 9.92$, $p = 0.002$, $\eta^2 = 0.06$. This likely reflected that questions about visual details were somewhat more difficult (with an average of 70% correct) than questions about auditory details (75% correct). There was also a significant effect of interview condition, $F_{(3, 116)} = 8.39$, $p < 0.001$, $\eta^2 = 0.18$; children performed better in the blank-screen and eyes-closed conditions than in the visual-distraction and auditory-distraction conditions (see **Table 1**). Finally, there was a significant interaction between modality and condition, $F_{(3, 116)} = 14.54$, $p < 0.001$, $\eta^2 = 0.26$. Simple effects analyses showed that interview condition had a significant impact on correct responses about visual details of the witnessed event, $F_{(3, 116)} = 26.95$, $p < 0.001$, $\eta^2 = 0.41$, but did not significantly affect correct responses about auditory details ($F < 1$). Pairwise comparisons for visual details (Bonferroni-corrected $\alpha = 0.008$) confirmed that the differences between the blank-screen and eyes-closed conditions ($p = 0.34$) and between the visual- and auditory-distraction conditions ($p = 0.21$) were not significant, whereas all other differences between conditions were significant (all $ps < 0.001$). In sum, children in the blank-screen and eyes-closed conditions provided more correct responses about visual details than children in the visual- and auditory-distraction conditions. Moreover, eye-closure had large effects on correct recall of visual details, compared to both the visual-distraction ($d = 1.67$) and the auditory-distraction ($d = 1.81$) condition.

Table 1 | Mean proportions and standard deviations (in parentheses) of correct, incorrect, confabulated, and "don't know" responses to questions about visual and auditory details in the four interview conditions.

	Interview condition				
	Blank screen	Eyes closed	Visual distraction	Auditory distraction	Total
VISUAL DETAILS					
Correct	0.79 (0.12)	0.82 (0.12)	0.61 (0.13)	0.56 (0.16)	0.70 (0.17)
Incorrect	0.13 (0.11)	0.08 (0.09)	0.26 (0.13)	0.26 (0.16)	0.18 (0.15)
Confabulated	0.02 (0.06)	0.01 (0.03)	0.03 (0.05)	0.03 (0.08)	0.02 (0.06)
"Don't know"	0.06 (0.09)	0.08 (0.09)	0.10 (0.10)	0.14 (0.12)	0.09 (0.10)
AUDITORY DETAILS					
Correct	0.76 (0.16)	0.73 (0.16)	0.75 (0.17)	0.76 (0.16)	0.75 (0.16)
Incorrect	0.12 (0.13)	0.10 (0.16)	0.12 (0.11)	0.11 (0.11)	0.11 (0.13)
Confabulated	0.03 (0.06)	0.03 (0.05)	0.03 (0.05)	0.03 (0.05)	0.03 (0.06)
"Don't know"	0.07 (0.10)	0.12 (0.11)	0.09 (0.10)	0.08 (0.07)	0.09 (0.10)

INCORRECT RESPONSES

Prior to analysis, the incorrect-response data were square-root transformed to reduce positive skew and leptokurtosis. The ANOVA revealed significant effects of interview condition, $F_{(3, 116)} = 7.20$, $p < 0.001$, $\eta^2 = 0.16$, modality of encoded information, $F_{(1, 116)} = 26.31$, $p < 0.001$, $\eta^2 = 0.16$, and a significant interaction between the two, $F_{(3, 116)} = 7.34$, $p < 0.001$, $\eta^2 = 0.13$ (see **Table 1**). Simple effects analyses revealed that interview condition had a significant impact on incorrect responses about visual details, $F_{(3, 116)} = 18.02$, $p < 0.001$, $\eta^2 = 0.32$, but not on incorrect responses about auditory details ($F < 1$). Pairwise comparisons for visual details (Bonferroni-corrected $\alpha = 0.008$) confirmed that the differences between the blank-screen and eyes-closed conditions ($p = 0.06$) and between the visual- and auditory-distraction conditions ($p = 0.62$) were not significant, whereas all other differences between conditions were significant (all $ps < 0.001$). In sum, children in the blank-screen and eyes-closed condition gave fewer incorrect responses about visual details than children in the visual- and auditory-distraction conditions. Eye-closure had large effects on incorrect recall of visual details, compared to both the visual-distraction ($d = -1.62$) and the auditory-distraction ($d = -1.36$) condition.

CONFABULATIONS

Kruskal-Wallis tests revealed no significant effects of interview condition on the total number of confabulations [$H_{(3)} = 0.70$, $p = 0.87$], confabulations about visual details [$H_{(3)} = 1.09$, $p = 0.79$], or confabulations about auditory details [$H_{(3)} = 0.51$, $p = 0.93$]. **Table 1** shows that children provided very few confabulations overall. Thus, interpretation of these findings is difficult due to floor effects.

"DON'T KNOW" RESPONSES

Kruskal-Wallis tests revealed significant effects of interview condition on the total number of DK responses [$H_{(3)} = 9.18$, $p = 0.02$] and on the number of DK responses to questions about visual details [$H_{(3)} = 8.11$, $p = 0.04$], but not on DK responses to questions about auditory details [$H_{(3)} = 5.71$, $p = 0.12$]. Mann-Whitney tests were used to follow up the significant effects. For both total and visual DK responses, only the contrast between the blank-screen condition and the auditory-distraction condition was significant at a Bonferroni-corrected α-level of.008 (total: $U = 260$, $p = 0.003$, $\eta^2 = 0.14$; visual: $U = 280$, $p = 0.007$, $\eta^2 = 0.12$). In sum, children in the blank-screen condition provided fewer DK responses about visual details than children in the auditory-distraction condition ($d = -0.56$).

DISCUSSION

We found that eye-closure (or looking at a blank screen) during recall substantially increased correct responses, and substantially decreased errors, for recall of visual information about the witnessed event, as compared to conditions in which children were exposed to visual and auditory distractions during the interview. Our findings with children only partly replicated Vredeveldt et al.'s (2011) findings with adults. Thus, we found a general effect of sensory distractions on recall of visual details, but we did not find a general effect on recall of auditory details. We also did not replicate their modality-specific effect (i.e., that recall of visual details was most impaired by visual distractions and that recall of auditory details was most impaired by auditory distractions).

In terms of visual distractions, our findings with children are in line with some findings with adults, but not others. First, Perfect et al. (2012) manipulated visual distractions directly, and found that increased visual distractions led to fewer correct and more incorrect responses about both visual and auditory details in the event. We replicated this finding with regards to visual details, but did not find that visual distractions impaired recall of auditory details. Second, some adult studies manipulating eye-closure have found that eye-closure improved recall of both visual and auditory details (Perfect et al., 2008 Experiments 3–5; Vredeveldt and Penrod, 2012). However, other studies have found that eye-closure had selective benefits for recall of visual details only (Perfect et al., Experiment 2; Vredeveldt et al., 2012, Experiment 1; Vredeveldt et al., 2013). Similarly, in the present study, distractions in the interview environment only affected recall of visual details.

In terms of auditory distractions, our findings with children are partly in line with what Perfect et al. (2011) found for adults, namely that auditory distractions increased the number of errors for visual details. However, unlike Perfect et al. (2011), (a) auditory distractions in the present study also decreased the number of correct responses for visual details, and (b) auditory distractions did not impair recall of auditory details. The latter finding is in line with Vredeveldt et al. (2012, Experiment 2), who found that auditory distractions did not impair adults' recall of auditory details (although they also found that auditory distractions did not impair recall of visual details either, unlike the present study). In sum, our findings show that children perform better when they are interviewed in a silent environment. However, if it is not possible to conduct the interview in a silent environment, eye-closure during recall may help interviewees to overcome accuracy impairments caused by auditory distractions (Perfect et al., 2011). Future research should investigate whether this compensatory effect of eye-closure is also observed with children.

We found that distractions during the interview did not interfere with children's recall performance in a modality-specific way. Both auditory and visual distraction impaired participants' recall of visual details. It appears that closing their eyes or looking at a blank screen helped children to focus on the task of recalling visual information, while any type of external distraction had a disruptive effect. This might be explained in the light of a cognitive load hypothesis (Lavie and Tsal, 1994; Lavie, 2005; Lavie and Lin, 2009; Sweller et al., 2011), which suggests that people have a limited amount of cognitive resources they can devote to cognitive tasks. Therefore, performance on a cognitive task (such as attempting to retrieve information about a witnessed event) will be impaired by any concurrent tasks that require cognitive resources (such as monitoring the environment during the interview). Closing the eyes may be a way to reduce interference of external stimulation and reduce rememberers' cognitive load, both increasing the capability of the witness to focus on the memorial image and decreasing the burden of monitoring the environment for social cues (Bond and Titus, 1983). Given that children are particularly affected by the social and environmental components of an interview (e.g., characteristics of the interviewer, social cues and types of requests; see Krähenbühl and Blades, 2006; Quas et al., 2007), a reduction in cognitive load might explain the effect of eye-closure in increasing children's accuracy. In the present study, children's performance was affected by any form of distraction, probably because they experienced difficulties on focusing and sustaining attention over time (Ruff and Rothbart, 1996; Dowsett and Livesey, 2000; NICHD Early Child Care Research Network, 2005). Unlike adults, where a modality-specific effect was found, visual/auditory distraction had a general disruptive effect on children's performance.

An alternative account emerges from developmental studies on working memory and specifically on the "storage and processing" functions of the central executive (see Gathercole, 2000, for a review). According to this explanation, as the individual has to process incoming data (e.g., visual/ auditory distraction) and at the same time recall information, there will be a lower amount of activation available to support processing. Case et al. (1982) suggested that the total processing space available remains constant over development and it is the operational efficiency that is increased over time. Our results suggest that the latter was still inadequate in our sample of children, therefore any form of distraction interfered with performance.

Our findings also suggest that children's recall of visual details is more vulnerable to external distractions than their recall of auditory details. Why this is the case, is not clear. Perhaps, this effect is related to task demand. Although our questions about visual and auditory details were carefully designed, it is possible that our participants found it easier to respond to the latter, as illustrated by their ability to sustain consistently high memory accuracy for auditory details, even when faced with distractions during the interview. A second possible explanation may relate to the study material. In our experiment, auditory material was mostly presented as spoken by an actor within a social interaction. This may have produced a bimodal advantage (i.e., audio-visual), resulting in an enhancement of participants' performance as compared to visual material that was presented unimodally (see Mastroberardino et al., 2008 for a review).

In sum, our findings show that eye-closure is an ecologically valid and inexpensive way of helping children to recall the visual aspects of an event. We found that eye-closure resulted in sizeable benefits for children's recall of visual information. One of the most important (and unique) selling points of the eye-closure instruction is that it not only increases correct recall, but also decreases incorrect recall. Further, unlike many other interview protocols, it does not require any training or additional interview time, and can be easily implemented in forensic settings. Nevertheless, when questioning children one has to take into account that they do not report spontaneously most of the information they remember and that they have to be prompted using appropriate questioning (Goodman and Melinder, 2007; Melinder et al., 2010). Therefore, more research needs to be conducted into possible associations between eye-closure and other interview strategies to enhance children's memory performance.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: http://www.frontiersin.org/journal/10.3389/fpsyg.2014.00241/abstract

REFERENCES

Bond, C. F., and Titus, L. J. (1983). Social facilitation: a meta analysis of 241 studies. *Psychol. Bull.* 94, 265–292. doi: 10.1037/0033-2909.94.2.265

Case, R., Kurland, D. M., and Goldberg, J. (1982). Operational efficiency and the growth of short term memory span. *J. Exp. Child Psychol.* 33, 386–404. doi: 10.1016/0022-0965(82)90054-6

Clarke, C., and Milne, R. (2001). *National Evaluation of the PEACE Investigative Interviewing Course.* Police Research Award Scheme. London: Home Office.

Dando, C., Wilcock, R., Milne, R., and Henry, L. (2009). A modified cognitive interview procedure for frontline police investigators. *Appl. Cogn. Psychol.* 23, 698–716. doi: 10.1002/acp.1501

Doherty-Sneddon, G., Bruce, V., Bonner, L., Longbotham, S., and Doyle, C. (2002). Development of gaze aversion as disengagement from visual information. *Dev. Psychol.* 38, 438–445. doi: 10.1037/0012-1649.38.3.438

Doherty-Sneddon, G., and Phelps, F. G. (2005). Gaze aversion: a response to cognitive or social difficulty? *Mem. Cogn.* 33, 727–733. doi: 10.1111/j.1469-7610.2011.02481.x

Dowsett, S. M., and Livesey, D. J. (2000). The development of inhibitory control in preschool children: effects of 'executive skills' training. *Dev. Psychobiol.* 36, 161–174. doi: 10.1002/(SICI)1098-2302(200003)36:23.0.CO;2-0

Enns, J. T. (1990). "Relations between components of visual attention," in *The Development of Attention: Research and Theory*, ed J. T. Enns (Amsterdam: Elsevier Science), 139–158.

Fisher, R. P., and Geiselman, R. E. (1992). *Memory Enhancing Techniques for Investigative Interviewing: The Cognitive Interview*. Springfield, IL: C.C. Thomas.

Gathercole, S. (2000). The development of memory. *J. Child Psychol. Psychiatry* 39, 3–27. doi: 10.1111/1469-7610.00301

Glenberg, A. M., Schroeder, J. L., and Robertson, D. A. (1998). Averting the gaze disengages the environment and facilitates remembering. *Mem. Cogn.* 26, 651–658. doi: 10.3758/BF03211385

Goodman, G. S., and Melinder, A. (2007). Child witness research and forensic interviews of young children: a review. *Leg. Criminol. Psychol.* 12, 1–19. doi: 10.1348/135532506X156620

Kebbell, M., Milne, R., and Wagstaff, G. (1999). The cognitive interview: a survey of its forensic effectiveness. *Psychol. Crime Law* 5, 101–115. doi: 10.1080/10683169908414996

Kebbell, M. R., and Wagstaff, G. F. (1999). "The effectiveness of the cognitive interview," in *Interviewing and Deception*, eds D. Canter and L. Allison (Aldershot: Ashgate), 25–39.

Krähenbühl, S., and Blades, M. (2006). The effect of interviewing techniques on young children's responses to questions. *Child Care Health Dev.* 32, 321–331. doi: 10.1111/j.1365-2214.2006.00608.x

Lavie, N. (2005). Distracted and confused? Selective attention under load. *Trends Cogn. Sci.* 9, 75–82. doi: 10.1016/j.tics.2004.12.004

Lavie, N., and Lin, Z. (2009). The role of perceptual load in object recognition. *J. Exp. Psychol. Hum. Percept. Perform.* 35, 1346–1358. doi: 10.1037/a0016454

Lavie, N., and Tsal, Y. (1994). Perceptual load as a major determinant of the locus of selection in visual attention. *Percept. Psychophys.* 56, 183–197. doi: 10.3758/BF03213897

Markson, L., and Paterson, K. B. (2009). Effects of gaze-aversion on visual-spatial imagination. *Br. J. Psychol.* 100, 553–563. doi: 10.1348/000712608X371762

Mastroberardino, S., Natali, V., and Candel, I. (2012). The effect of eye closure on children's eyewitness testimonies. *Psychol. Crime Law* 18, 245–257. doi: 10.1080/10683161003801100

Mastroberardino, S., Santangelo, V., Botta, F., Marucci, F. S., and Olivetti Belardinelli, M. (2008). How the bimodal format of presentation affects working memory: an overview. *Cogn. Process.* 9, 69–76. doi: 10.1007/s10339-007-0195-6

Melinder, A., Alexander, K., Il Cho, Y., Goodman, G. S., Thoresen, C., Lonnum, K., et al. (2010). Children's eyewitness memory: a comparison of two interviewing strategies as realized by forensic professionals. *J. Exp. Child Psychol.* 105, 156–177. doi: 10.1016/j.jecp.2009.04.004

Memon, A., Wark, L., Bull, R. and Koehnken, G. (1997). Isolating the effects of the Cognitive Interview techniques. *Br. J. Psychol.* 88, 179–198. doi: 10.1111/j.2044-8295.1997.tb02629

Natali, V., Marucci. F. S., and Mastroberardino, S. (2012). Long-term memory effects of eye closure on children eyewitness testimonies. *Appl. Cogn. Psychol.* 26, 730–736. doi: 10.1002/acp.2853

NICHD Early Child Care Research Network. (2005). Predicting individual differences in attention, memory, and planning in first graders from experiences at home, child care, and school. *Dev. Psychol.* 41, 99–114. doi: 10.1037/0012-1649.41.1.99

Perfect, T. J., Andrade, J., and Eagan, I. (2011). Eye-closure reduces the cross-modal memory impairment caused by auditory distraction. *J. Exp. Psychol. Learn. Mem. Cogn.* 37, 1008–1013. doi: 10.1037/a0022930

Perfect, T. J., Andrade, J., and Syrett, L. (2012). Environmental visual distraction during retrieval affects the quality, not the quantity, of eyewitness recall. *Appl. Cogn. Psychol.* 26, 296–300. doi: 10.1002/acp.1823

Perfect, T. J., Wagstaff, G. W., Moore, D., Andrews, B., Cleveland, V., Newcombe, S. M. et al. (2008). How can we help witness to remember more? It's an (Eyes) open and shut case. *Law Hum. Behav.* 32, 314–324. doi: 10.1007/s10979-007-9109-5

Phelps, F. G., Doherty-Sneddon, G., and Warnock, H. (2006). Helping children think: gaze aversion and teaching. *Br. J. Dev. Psychol.* 24, 577–588.

Quas, J. A., Malloy, L. C., Melinder, A., Goodman, G., D'Mello, M., and Schaaf, J. (2007). Developmental differences in the effects of repeated interviews and interviewer bias on young children's event memory and false reports. *Dev. Psychol.* 43, 823–837. doi: 10.1037/0012-1649.43.4.823

Ruff, H. A., and Rothbart, M. K. (1996). *Attention in Early Development: Themes and Variations*. New York, NY: Oxford University Press. doi: 10.1093/acprof:oso/9780195136326.001.0001

Sweller, J., Ayres, P., and Kalyuga, S. (2011). *Cognitive Load Theory*. New York, NY: Springer. doi: 10.1007/978-1-4419-8126-4

Vredeveldt, A., Baddeley, A. D., and Hitch, G. J. (2012). The effects of eye-closure and "ear-closure" on recall of visual and auditory aspects of a criminal event. *Eur. J. Psychol.* 8, 284–299. doi: 10.5964/ejop.v8i2.472

Vredeveldt, A., Baddeley, A., and Hitch, G. J. (2013). The effectiveness of eye-closure in repeated Interviews. *Leg. Criminol. Psychol.* doi: 10.1111/lcrp.12013. [Epub ahead of print].

Vredeveldt, A., Hitch, G. J., and Baddeley, A. (2011). Eye-closure helps memory by reducing cognitive load and enhancing visualisation. *Memo. Cogn.* 39, 1253–1263. doi: 10.3758/S13421-011-0098-8

Vredeveldt, A., and Penrod, S. D. (2012). Eye-closure improves memory for a witnessed event under naturalistic conditions. *Psychol. Crime Law* 19, 893–905. doi: 10.1080/1068316X.2012.700313

Wagstaff, G. F., Wheatcroft, J. M., Burt, C. L., Pilkington, H. J., Wilkinson, K., and Hoyle, J. D. (2011a). Enhancing witness memory with focused meditation and eye-closure: assessing the effects of misinformation. *J. Police Crim. Psychol.* 26, 152–161. doi: 10.1007/s11896-010-9082-7

Wagstaff, G. F., Wheatcroft, J. M., Caddick, A. M., Kirby, L. J., and Lamont, E. (2011b). Enhancing witness memory with techniques derived from hypnotic investigative interviewing: focused meditation, eye-closure, and context reinstatement. *Int. J. Clin. Exp. Hypn.* 59, 146–164. doi: 10.1080/00207144.2011.546180

Wais, P. E., Rubens, M. T., Boccanfuso, J., and Gazzaley, A. (2010). Neural mechanisms underlying the impact of visual distraction on retrieval of long-term memory. *J. Neurosci.* 30, 8541–8550. doi: 10.1523/JNEUROSCI.1478-10.2010

Yuille, J., Hunter, R., Joffe, R., and Zaparnuik, J. (1993). "Interviewing children in sexual abuse cases," in *Child Victims, Child Witnesses: Understanding and Improving Testimony*, eds G. Goodman and B. Bottoms (New York, NY: Guilford), 95–115.

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Inconsistent findings for the eyes closed effect in children: the implications for interviewing child witnesses

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A child who alleges that they have been the victim of a crime will be interviewed by police officers. During a police interview it is important that the interviewer obtains the most accurate testimony possible from the child. Previous studies have shown that if children have their eyes closed during an interview they sometimes report more correct information. This paper includes two studies. In Experiment 1 156 children experienced an event and were then questioned about it. Half the children answered with their eyes open and half with their eyes closed. The participants with eyes closed provided more correct information. In Experiment 2 152 children answered questions in different conditions including eyes open and eyes closed conditions. In contrast to Experiment 1 there was no beneficial effect for the eyes closed condition. These inconsistent results are discussed with reference to actual police interviews. It is suggested that until there has been more research into eyes closed procedures caution should be taken in recommending such procedures for police interviews with children.

Keywords: child eyewitness, eyes closed effect, police interviews, eyewitness testimony, child interviews, children's testimony

INTRODUCTION

Children may be interviewed in many contexts and a particularly important one is when they are interviewed as part of a forensic investigation. Children may be interviewed because they have been witnesses to a crime or because they have been the victim of a crime (Ministry of Justice, 2011). In cases of physical or sexual abuse a child may be the only witness, because the nature of the crime means that evidence from other witnesses is unlikely, and in many cases there may be a lack of other evidence, such as medical signs (Jong, 1996). For example, Kyriakidou (2012) examined every case of child maltreatment in the Republic of Cyprus for a 5-year period (2004–2009) and found that in two-thirds of these cases the only source of evidence was the child's testimony itself. Therefore a child's testimony can be crucial for investigating an alleged crime and it is important that police interviewers obtain the most complete and accurate responses from a child witness.

Several questioning techniques have been developed for forensic interviewing. These include the Cognitive Interview (Fisher and Geiselman, 1992); Achieving Best Evidence (ABE) (Ministry of Justice, 2011); the P.E.A.C.E. (Preparing and planning, Engage and explain, Account, Closure and Evaluate) guidelines (Clarke and Milne, 2001), and the National Institute of Child Health and Human Development (NICHD) protocol (Lamb et al., 2011). Procedures like the NICHD protocol have been extensively investigated and have been shown to improve the quality of interviews with children (Lamb et al., in press). Nonetheless, the procedures may not always be fully implemented by interviewers (Hershkowitz et al., 2005; Westcott and Kynan, 2006) and there is still a need to consider interview techniques that can be used easily with children. This has led to research into the effectiveness of eyes closed procedures.

Adult eyewitnesses provide more accurate information, without an increase in incorrect information, when answering questions with their eyes closed (Wagstaff et al., 2004; Perfect et al., 2008; Vredeveldt et al., 2012; Vredeveldt and Penrod, 2012). In a series of five experiments with adults, Perfect et al. (2008) investigated the effects of an eye closure condition for recall of different types of presentation (video or live), question modality (visual or auditory) and question type (free recall or specific). In three of the experiments participants were shown different video clips and in the other two experiments participants took part in a live event. The participants were then interviewed while keeping their eyes open or closed. Overall Perfect et al. found that participants recalled more accurate information in conditions when they had their eyes closed, and this was particularly true for the recall of visual information. Similar effects for improved accuracy were found by Perfect et al. (2011), who replicated the improved accuracy of recall with eye closure, and also found that eye closure during recall tended to reduce the negative effects of auditory noise. The results of these studies suggest that eye closure is an effective procedure for increasing the accurate information provided by adult witnesses.

Similar positive findings have been found in studies with children. Mastroberardino et al. (2012) interviewed 6- and 11-year-olds in both eyes open and eyes closed conditions immediately after the children had watched a video clip from the film "Jurassic Park". Children were asked for free recall and also asked specific questions. Children with their eyes closed recalled more accurate details without an increase of inaccurate details when they were asked specific questions, though there was no effect of eye closure on free recall. Natali et al. (2012) showed 11-year-olds a bank robbery from the film "Dog Day Afternoon" and tested the children's recall for the first time immediately after seeing the film, and then tested their recall a second time after a delay of a week. Children who had their eyes closed provided more correct information in free recall, and answered specific questions more accurately both immediately and after the delay.

Children and adults may be better at answering questions with their eyes closed than with their eyes open for several reasons. When interviewees have their eyes open the interview task has a dual aspect. The interviewee needs to generate answers to the questions at the same time as monitoring the environment. An interviewee has to pay attention to the interviewer and to any other people in the room, as well as taking into account any distractions, like noise, in the environment. According to the cognitive load hypothesis people have a limited amount of cognitive resources in any task, and the effort of monitoring the environment may interfere with the effort of retrieving information and reduce the quantity or accuracy of the responses (Glenberg, 1997). Closing eyes has the effect of removing or reducing the stimuli from the environment that a person experiences, thereby changing the nature of the task from a dual to a single task so that an interviewee can concentrate their cognitive resources on just the retrieval of relevant information (Glenberg et al., 1998; Perfect et al., 2008). Adults perform better in tasks when the distracting effect of the environment is lessened, for example, Glenberg et al. found that adults' recall was better when they were asked to look at a static image rather than a more complex moving image, and Perfect et al. (2012) found that increased distraction led to a reduction in adults' recall accuracy.

Children may be particularly affected by environmental cues in an interview context, because an interview involves face-to-face interaction with an adult. This interaction involves a cognitive load as the child has to process information from the interviewer's face, and the child also has to take into account any social cues implicit in another person's gaze (Doherty-Sneddon et al., 2001; Doherty-Sneddon and Phelps, 2005). Children may look away from an interviewer while they consider their answer, especially when responding to more difficult questions (Doherty-Sneddon et al., 2002, 2007; Doherty-Sneddon, 2004), and looking away is one way that children can disengage from the environment if that environment is distracting them from focusing on the retrieval of appropriate information (Doherty-Sneddon and Phelps, 2005). Asking children to close their eyes may have a similar effect by getting children to disengage from the environment during an interview.

Eye closure might also benefit recall if closing eyes results in better visual imagery (Ganis et al., 2004), and if in turn better visual imagery helps children to retrieve more visual information about a past event (Vredeveldt et al., 2011). If this is the case answering questions with eyes closed should particularly benefit the recall of visual details, but might not necessarily improve the recall of other (e.g., auditory) details, in which case eye closure would be modality specific.

If children give more information, and more accurate information when answering questions with their eyes closed, this has implications for interviewing children in forensic contexts. Asking children to keep their eyes closed seems to be a procedure that can be implemented easily. The procedure does not require interviewer training, or any alteration to the existing police guidelines for interviewing witnesses (Ministry of Justice, 2011) other than asking children to close their eyes.

As noted above there have only been a couple of published studies with children (Mastroberardino et al., 2012; Natali et al., 2012) both of which found positive effects when children answered specific questions about a film extract with their eyes closed. We carried out a similar study (Experiment 1, below), but unlike the previous studies that have examined children's recall of films we used an event that combined live and video elements so that children saw an actual event that was acted out in front of them. We used such an event to approximate more closely to a real life eyewitness experience. The children were interviewed either soon after the event or a week later.

Given the previous positive results for eye closure (Mastroberardino et al., 2012; Natali et al., 2012) we expected children would recall more information when interviewed with eyes closed than with eyes open immediately after the event. Following previous findings for both adults and children that eyes closed interviews are still beneficial after a delay (Natali et al., 2012; Vredeveldt et al., 2013) we expected children to recall more when interviewed with eyes closed than with eyes open a week after the event.

EXPERIMENT 1

METHODS

Participants

Experiment 1 included 156 children aged 6–12 years, mean age 9 years (78 girls and 78 boys) from schools in Cyprus. The children were a random sample of the children available in schools at the time of testing. The children experienced an event and were then questioned about it. Children saw the event in groups of between 10 and 20 participants. Seventy-eight children interviewed with their eyes closed and 78 with their eyes open. In the immediate condition 79 children were interviewed within an hour of seeing the event. In the delay condition, 77 children were interviewed 7 days after the event.

Ethical approval was given by the Department of Psychology, University of Sheffield. Permission to work in schools was provided by the Ministry of Education in Cyprus and the parents of children gave informed consent for their children to take part.

Materials

The 10 min event was a combination of a scripted live performance (6 min) and a video (4 min) performed by three assistants (who took no further part in the study). In the live performance an assistant called "Kim" took participants to a room where she started to show them how to do a magic trick. While Kim was demonstrating the trick, her friend "Mik" ran into the room and said that she was upset because she had lost her favorite jacket and that she might have left it at Kim's house the evening before. Mik then described the jacket. Kim calmed Mik down and said that she had a video from the previous evening that might show what had happened to the jacket. Participants were asked if they minded watching the video. The video showed Kim and Mik at a table in a dining room where they were eating pizza and talking. Mik's jacket was shown hanging on a peg. Kim and Mik left the room to get ice cream, and while they were away, a female entered the dining room and took the jacket. When Kim and Mik returned they continued with their meal without noticing that the jacket had gone. Having seen the video Mik was shocked and said that she would go to the police. She then left the room. Kim apologized for the interruption and then finished the demonstration of the magic trick.

Procedure

After the event participants were questioned individually. The interviewer had not been present at the event. The study was carried out in Greek and therefore quotes are translations from the original. In the immediate condition the interviewer started by saying, "I would like to ask you some questions about the event you saw today." In the delay condition the interviewer said, "I would like to ask you some questions about the event you saw last week." In the eyes open condition children received no instructions about where they should look during the interview. In the eyes closed condition the interviewer added, "During the questioning I would like you to keep your eyes closed." If children opened their eyes during the interview the interviewer reminded them to keep their eyes closed. In both conditions children were told, "If you don't know the answer to a question, it's okay, you can say that you don't know the answer." The interviews were audio taped for later analysis.

Twenty-eight questions were used in the interview (see Appendix 1 in Supplementary material). Question 1 was a free recall question asking participants to freely recall the event and question 2 was an open-ended question that asked for a description of the person who stole the jacket. The intention was to analyse these questions separately, but several children included information about the person who stole the jacket when answering question 1, and therefore children's responses to both questions were combined and will be referred to as the free recall. The rest of the questions were specific ones that required children to generate an answer. There were no yes/no or forced choice questions. Twelve of the specific questions were about visual information (e.g., "What color was Kim's t-shirt when she was showing you the magic trick?"). Visual questions are numbered 5–16 in the Supplementary material. Fourteen of the specific questions were about auditory information (e.g., "What was the name of the girl who demonstrated the magic trick to you?"). Auditory questions are questions numbered 3–4 and 17–28 in the Supplementary material. The experiment was designed with equal numbers of visual and auditory questions, but two visual questions had to be dropped from the analysis. One visual question asked the children where they went to be interviewed and the other asked who took the child to the interview, but for practical reasons children were questioned in different places in schools and were taken there by different people. Children's ability to answer these questions partly depended on how familiar they were with the specific interview place or with the person taking them, and therefore the answers could not be coded consistently.

Questions 1–4 were asked first and in the same order for all participants. The rest of the questions, 5–28, were asked in a different random order for each participant. When the interview was completed the child was thanked and was asked not to talk about the interview with other children. We could not check whether children discussed the event or the interview with other children, but even if they did so there was no reason to believe that the number of children who discussed the event in the eyes closed condition would be more (or less) than the children in the eyes open condition.

Coding

As noted above the responses to questions 1 and 2 were combined and scored for the number of items of information provided, number of correct details, number of incorrect details, and confabulations. For information in a response to be considered as a relevant detail (correct or incorrect) it had to provide details about time, people (e.g., names, gender), objects (e.g., food, clothes), places (e.g., house, living room) or actions (e.g., "took the jacket"). These details were chosen because an analysis of actual police interviews (Kyriakidou, 2012) had shown that such details were frequently requested by interviewers. For example, one child, in free recall, said, "Give me a moment to remember. I remember something now. I remember two girls they were in a house and they ordered pizza. They were talking about different stuff until they left the house and another girl came in the house and took the jacket." In this extract the child mentioned 8 details (underlined). Of these details, one, "they left the house" was incorrect; the others were correct. There were almost no confabulations, and therefore confabulations were ignored.

Answers to specific questions were scored as correct if a participant gave an appropriate response. Appropriate responses to specific questions were defined prior to the interview. If an answer to a specific question could include two potential details, children had to mention at least one detail in their answer to be correct, and for answers that could include three or more details children had to give at least two details. Children's answers were only scored as correct if they met these criteria. All other responses to specific questions (including wrong answers, and "don't knows") were coded as incorrect, because such answers provide no forensic evidence. Two coders coded correct items in free recall and correct responses to specific questions of the interviews. Cohen's kappa was run to determine the level of agreement. There was good agreement for free recall, $k = 0.383$ ($p < 0.001$) and for specific questions $k = 0.394$ ($p < 0.001$).

RESULTS

Table 1 summarizes how the interview conditions (eyes closed or eyes open) and delay conditions (immediate interview or interview after 1 week) influenced children's recall in free recall and for the specific questions.

Free recall

Number of details. To investigate the effects of interview and delay conditions on the number of details given in free recall a 2 interview (eyes closed, eyes open) × 2 delay (immediate, 1 week) ANOVA was carried out. The interview influenced the number of details provided to questions 1 and 2 [$F_{(1, 147)} = 4.39$, $p = 0.038$, $\eta^2 = 0.029$]. Children provided more details with their eyes closed ($M = 8.9$, $SD = 4.9$) than with their eyes open ($M =$

Table 1 | Mean scores for interview condition and for delay in Experiment 1.

	Free recall *M* (*SD*)			Specific questions *M* (*SD*)		
	No. of details	Correct details	Incorrect details	Correct answers	Correct visual	Correct auditory
Eyes closed	8.9 (4.9)	7.8 (4.6)	1 (1.3)	11.1 (3.6)	6.2 (1.8)	4.9 (2.4)
Eyes open	7.2 (5.5)	5.9 (4.7)	1.7 (3.9)	10 (3.5)	5.7 (1.8)	4.3 (2.2)
Immediate	8.9 (5.8)	7.9 (5.2)	1.4 (3.9)	11.7 (3.8)	6.3 (1.8)	5.5 (2.5)
Week delay	7.2 (4.5)	5.9 (4)	1.3 (1.4)	9.4 (3)	5.7 (1.8)	3.7 (1.6)

7.2, $SD = 5.5$). There was an effect of delay [$F_{(1,\ 147)} = 4.13$, $p = 0.044$, $\eta^2 = 0.66$]. Children provided more details in the immediate condition ($M = 8.9$, $SD = 5.8$) than after a week ($M = 7.2$, $SD = 4.5$), but there was no interaction between interview and delay.

Number of correct details. A 2 interview (eyes closed, eyes open) × 2 delay (immediate, 1 week). ANOVA was conducted on the number of correct details, there was an interview effect [$F_{(1,\ 147)} = 6.97$, $p = 0.009$, $\eta^2 = 0.05$]. Children provided more correct details with their eyes closed ($M = 7.8$, $SD =$ 4.6) than open ($M = 5.9$, $SD = 4.7$). There was an effect of delay [$F_{(1,\ 147)} = 7.35$, $p = 0.008$, $\eta^2 = 0.48$] with children in the immediate condition recalling more correct details ($M = 7.9$, $SD = 5.2$) than children in the delay condition ($M = 5.9$, $SD =$ 4). There was no interaction.

Number of incorrect details. There was no difference in the number of incorrect details provided in the interview conditions [$F_{(1,\ 147)} = 2.22$, $p = 0.139$, $\eta^2 = 0.02$]. There was no effect of delay and no interaction between interview and delay on the number of incorrect details.

Specific questions

There were 26 specific questions therefore the maximum possible correct score for each child was 26. A 2 interview (eyes closed, eyes open) × 2 delay (immediate, 1 week) ANOVA was carried out. There were more correct responses [$F_{(1,\ 152)} = 4.09$, $p = 0.045$, $\eta^2 = 0.03$] with eyes closed ($M = 11.1$, $SD = 3.6$) than with eyes open ($M = 10$, $SD = 3.5$). There was also an effect for delay [$F_{(1,\ 152)} = 18.81$, $p < 0.001$, $\eta^2 = 0.11$] with more correct answers in the immediate condition ($M = 11.7$, $SD = 3.8$) than after a week ($M = 9.4$, $SD = 3$). There was no interaction.

Visual questions. The maximum possible score for correct answers to visual questions was 12. A 2 interview (eyes closed, eyes open) × 2 delay (immediate, 1 week) ANOVA was conducted on the visual questions. Children provided more correct answers to visual questions with their eyes closed ($M = 6.2$, $SD = 1.8$) than with their eyes open ($M = 5.7$, $SD = 1.8$) [$F_{(1,\ 152)} = 0.04$, $p =$ 0.047, $\eta^2 = 0.03$]. There was no effect of delay [$F_{(1,\ 152)} = 3.66$, $p = 0.058$, $\eta^2 = 0.03$] and there was no interaction.

Auditory questions. The maximum possible number of correct answers for auditory questions was 14. A 2 interview (eyes closed, eyes open) × 2 delay (immediate, 1 week) ANOVA was carried out. Children's recall on the auditory questions was not influenced by the interview [$F_{(1,\ 152)} = 2.2$, $p = 0.14$, $\eta^2 = 0.03$]. Delay did have an effect on the accuracy of children's auditory answers [$F_{(1,\ 152)} = 27.26$, $p < 0.001$, $\eta^2 = 0.15$] as children gave more correct answers when questioned immediately after the event ($M = 5.5$, $SD = 2.5$) than when questioned a week later ($M = 3.7$, $SD = 1.6$).

DISCUSSION

In Experiment 1 children gave more details and more correct details about the event in free recall when they had their eyes closed, both immediately after the event and after a delay of a week. Keeping eyes closed had no effect on the number of incorrect details reported. For specific questions children answered more visual questions correctly when they had their eyes closed, both immediately and after the delay, and although the increase in the number of specific visual questions answered correctly was small in this experiment, the same effect could be important in an actual interview when children are asked much larger numbers of questions (see General discussion). There was no effect of eye closure when children answered auditory questions.

These results partially support previous research with children. Children's better performance with eyes closed in free recall was similar to Natali et al. (2012) who also found that children who had their eyes closed were more accurate when asked for free recall of a film they had seen, both immediately after seeing the film and a week later. However when Mastroberardino et al. (2012) tested children's free recall of a film immediately after viewing it they did not find better performance from children with their eyes closed. Adults generally perform better in free recall in eyes closed conditions (Perfect et al., 2008, Experiments 3 and 5; Vredeveldt and Penrod, 2012), but as yet the limited evidence from studies with children does not show a consistent benefit of eye closure in free recall. It is difficult to reconcile the results from Experiment 1 and Natali et al. with those of Mastroberardino et al. because all three studies used similar procedures, and if eyes closed has a beneficial effect it should be apparent in all cases of free recall.

Mastroberardino et al. (2012) found that children with eyes closed performed better than children with their eyes open when answering cued recall questions. The questions in Mastroberardino et al. asked children to provide additional details about the information they had already included in their free recall and could therefore have been a mix of questions about visual or auditory details. In Experiment 1 we distinguished between specific questions about the visual and auditory information in the event. Although we found that children in the eyes closed condition gave more correct responses to visual questions there was not a similar effect for auditory questions. This could suggest that for children eye closure is only effective in contributing to the recall of visual information and that eye closure is modality specific (Vredeveldt et al., 2011). But this suggestion cannot be maintained in the light of Natali et al.'s (2012) study because they found that eyes closed improved children's accuracy when answering both visual and auditory questions.

When children do perform better with their eyes closed it could be because eye closure allows children to focus on the task of answering questions by reducing distracting information from the environment (Perfect et al., 2008). In particular, a child with their eyes closed can avoid any distracting social cues that may be given by the interviewer (Doherty-Sneddon et al., 2001; Doherty-Sneddon and Phelps, 2005). However, in the course of Experiment 1 we noted that children in the eyes closed condition had difficulty keeping their eyes closed. Remembering to keep their eyes closed requires effort that could have distracted the children from answering the questions, and when an interviewer has to remind a child to close their eyes this interrupts the interview and the child's focus on the questions. Greater distraction may reduce recall (Glenberg et al., 1998; Doherty-Sneddon and Phelps, 2005; Perfect et al., 2012) and have a negative effect on children's performance. Therefore in Experiment 2 we considered whether children's recall was enhanced if they only closed their eyes at particular times during an interview. In this way children might still benefit from the positive effects of eye closure without being distracted by the effort of keeping their eyes closed continuously.

In Experiment 2 there were 4 interview conditions. In the first condition children were not given any instructions about closing their eyes and kept their eyes open throughout the interview. Therefore children had their eyes open during questioning and during answering and this will be referred to as the EO/EO condition.

Children in a second condition were asked to keep their eyes closed throughout the whole of the interview during both questioning and answering (EC/EC). Children in the EC/EC condition were expected to perform better than children in the EO/EO condition, in line with the results from Experiment 1.

In a third condition (EO/EC) children kept their eyes closed only while answering a question. In this condition children could benefit from seeing non-verbal cues from the interviewer that might increase the child's understanding of the question (Doherty-Sneddon and Kent, 1996), but were not distracted by the interviewer or external factors when they answered with their eyes closed (Doherty-Sneddon et al., 2001; Phelps et al., 2006) so we expected children would perform better when answering specific questions in the EO/EC condition than in the EO/EO condition.

Children in the fourth condition (EC/EO) closed their eyes only while listening to a question. Children in this condition were expected to perform no better than those in the EO/EO condition, because in the EC/EO condition they did not have the advantage of seeing the interviewer during the questioning, but did have the disadvantage of seeing the interviewer when answering.

EXPERIMENT 2

METHODS

Participants

The study took place in Cyprus. There were 152 children (88 girls and 64 boys) aged between 9 and 13 years with a mean age 10.6 years (SD = 0.98). There were 39 children in the EO/EO condition, 39 in the EC/EC condition, 37 in the EO/EC condition, and 37 in the EC/EO condition. There was a similar age range and approximately equal numbers of girls and boys in each condition. Ethical permission was obtained from the Psychology Department of the University of Sheffield. Permission to interview the children was obtained from the Ministry of Education in Cyprus, the principals of each primary school and from the parents or guardians of each child.

Materials

Children were shown a video, in Greek, lasting 5 min 50 s called "Pet Shop" by Michael Gabriel Zenelis. The film begins by showing the owner of a pet shop taking care of the animals in the shop. The owner notices that one of the dogs has a problem with its leg. The dog is put on one side and the owner makes a telephone call asking his colleague to come to fetch the dog because it is disabled and unsuitable for selling. Meanwhile, in a nearby park, a group of boys are playing basketball. When the ball goes out of the playground it rolls in front of the main character of the film. This boy is counting his money and he refuses to join in with the other children when they ask him to play. The boy goes into the pet shop and wants to buy a particular dog, which is too expensive for him. Then the boy asks how much the disabled dog costs. The owner initially refuses to sell the dog because it has a damaged leg and it will not be the kind of pet the child wants. The child finally buys the dog. As the child is leaving the pet shop the owner realizes that the child is limping and also has a damaged leg.

Procedure

The children watched the video in groups of 5–10. Immediately after having seen the video, they were randomly divided into each of the four conditions. The children were then interviewed individually. Children in the EO/EO condition were asked to keep their eyes open throughout the whole interview. Children in the EC/EC condition were asked to keep their eyes closed during the whole interview. In the EO/EC condition children kept their eyes closed only while answering and in the EC/EO condition they closed their eyes only when listening to the questions. If children opened their eyes at times when their eyes should have been closed the children were reminded to close them.

Children were asked a single free recall question at the beginning of the interview (see question 1 in Appendix 2 in Supplementary material), and then 21 specific questions (questions 2–22). Eleven of the specific questions were about visual aspects of the film and 10 were about auditory aspects. Specific questions were defined following ABE (Ministry of Justice, 2011) as questions that included why, what, who, when and how. The specific questions were asked in a different random order for each child.

Coding

For the free recall question (question 1) coding was carried out in the same as for questions 1 and 2 in Experiment 1. Details included references to time (e.g., it was daytime), to people (e.g., gender, names, ages) or animals (e.g., dogs, birds), to objects, (e.g., clothes, money), to places (e.g., houses, pet shop, cage) or to actions, (e.g., counting money, playing basketball, feeding animals). There were almost no confabulations in free recall, and therefore these were not analyzed.

Answers to each specific question were coded as correct, incorrect, or as "don't knows." What constituted a correct answer was agreed prior to the interviews. The maximum possible number of correct answers for specific questions was 21. Two coders coded open-ended and specific questions for one-third of the participants. The proportion of agreement between the two coders was examined via Cohen's kappa, and there was a good agreement for correct details in open-ended questions $k = 0.818$ ($p < 0.001$), for incorrect details in open ended questions $k = 0.526$ ($p < 001$) and for correct answers to specific questions $k = 0.703$ ($p < 0.001$).

RESULTS

Table 2 summarizes the findings. Free recall (question 1) was analyzed for the number of details provided, and for correct and incorrect details. One child was excluded, because they did not answer the free recall question. A One-Way ANOVA was performed to compare the number of details given by the children in each interview condition (EO/EO, EC/EC, EO/EC, EC/EO). There was no effect for interview [$F_{(3,\ 148)} = 0.39, p = 0.75, \eta^2 = 0.01$]. A similar ANOVA showed there was no effect of interview on the number of correct details reported [$F_{(3,\ 148)} = 0.37$, $p = 0.69$, $\eta^2 = 0.01$]. A third ANOVA found a significant effect of interview condition for incorrect details [$F_{(3,\ 148)} = 3.57$, $p = 0.016$, $\eta^2 = 0.07$]. *Post-hoc* tests showed that there were more incorrect answers in the EO/EO interviews ($M = 1.0$, $SD = 1.1$) than in the EO/EC condition ($M = 0.4$, $SD = 0.8$) ($p = 0.046$), though we note that there was only a very small mean number of incorrect details (1 or fewer) in any condition (see **Table 2**).

Participants were asked 21 specific questions, so the maximum possible score was 21. The mean scores are shown in **Table 2**. A One-Way ANOVA was conducted to compare the number of correct answers in each interview condition (EO/EO, EC/EC, EO/EC, EC/EO). The different interviews did not have an effect on the number of correct answers [$F_{(3,\ 148)} = 0.44$, $p = 0.73$, $\eta^2 = 0.01$]. A similar ANOVA was conducted on the number of incorrect answers given. The different interviews had no effect on the number of incorrect answers [$F_{(3,\ 148)} = 0.86, p = 0.47, \eta^2 = 0.02$]. A third ANOVA showed that "I don't know" responses were not affected by interview condition [$F_{(3,\ 148)} = 0.11$, $p = 0.95$, $\eta^2 = 0.01$].

DISCUSSION

In Experiment 2 the children performed equally in all four conditions, and did so regardless of whether they were being asked for free recall or answering specific questions about the event.

Contrary to our prediction children in the eyes closed condition (EC/EC) did not perform better in free recall than children in the eyes open condition (EO/EO). This finding is in contrast to the results from Experiment 1 and Natali et al. (2012). However, the lack of an eyes closed effect in free recall in Experiment 2 is the same as in Mastroberardino et al. (2012). In free recall children are simply asked to say as much as they can about the event they experienced, so the procedure for a free recall condition is similar in different experiments and comparable results might be expected. But, as yet, there are no consistent findings for the effects of eyes closed on children's free recall of events.

We had predicted that children would be better when they answered specific questions with their eyes closed throughout the interview (in condition EC/EC) than when they answered and kept their eyes open (condition EO/EO), but there was no difference in performance between these conditions. This was in contrast to Experiment 1 and the previous similar studies with children (Mastroberardino et al., 2012; Natali et al., 2012).

We predicted that children might be better at answering questions if they could look at the interviewer while the question was being asked, but closed their eyes while answering the question (in condition EO/EC) than when they had their eyes open all the time. This followed from research on eye gaze (e.g., Doherty-Sneddon and Kent, 1996; Doherty-Sneddon et al., 2001) that has shown that children can benefit from seeing an interviewer while being questioned, but often spontaneously look away from the interviewer while answering questions. However, we did not find that children were better in the EO/EC condition. This finding suggests that closing eyes does not have the same beneficial effect as gaze aversion while responding to questions. This may be because gaze aversion is a typical part of everyday interaction (Doherty-Sneddon, 2004) that requires little effort, but deliberate eye closure may require more effort and be distracting for children.

As expected, children who closed their eyes while listening to questions, but kept their eyes open while answering (EC/EO) did no better than children in the EO/EO condition. There is no reason to suppose that the EC/EO combination of eye closure would benefit children, because children who have their eyes open while answering questions are subject to similar distractions from the environment when responding as children who keep their eyes open all the time.

Experiment 2 did not find any beneficial effect of eyes closure in interviews with children, and did not support the more positive finding from Experiment 1. In the eyes closed condition (EC/EC) of Experiment 2 the children kept their eyes closed continuously, as they did in Experiment 1, but in Experiment 2 keeping eyes closed all the time did not result in the children performing better

Table 2 | Mean scores for each interview condition in Experiment 2.

	Free recall *M* (*SD*)			Specific questions *M* (*SD*)		
	No. of details	**Correct details**	**Incorrect details**	**Correct answers**	**Incorrect answers**	**Don't Knows**
Eyes open/eyes open	8.1 (5.0)	6.4 (3.8)	1.0 (1.1)	11.2 (2.5)	5.9 (2.3)	3.8 (2.4)
Eyes closed/eyes closed	7.3 (4.4)	6.8 (4.0)	0.5 (0.8)	11.4 (2.5)	5.9 (2.3)	3.6 (2.8)
Eyes open/eyes closed	7.6 (4.0)	7.2 (3.8)	0.4 (0.8)	11.4 (2.5)	5.5 (2.8)	3.8 (2.1)
Eyes closed/eyes open	8.3 (4.3)	7.4 (3.7)	0.9 (1.0)	10.8 (2.6)	6.4 (2.4)	3.8 (2.2)

than children who had their eyes open. The implications of these contrasting results is considered in the general discussion.

GENERAL DISCUSSION

If children can benefit from keeping their eyes closed in interviews this is an important finding. One of the most crucial contexts for interviewing children is when children are questioned as part of a police investigation, and in such a context the child might be the only source of evidence (Ministry of Justice, 2011; Kyriakidou, 2012). Therefore any procedure, like keeping eyes closed, that might elicit more evidence or more accurate evidence is important.

Eye closure may be an effective procedure with adults and this has led to researchers suggesting that eye closure can be an effective technique for interviewing adult eyewitnesses (e.g., Glenberg et al., 1998; Wagstaff et al., 2004; Perfect et al., 2008; Vredeveldt and Penrod, 2012; Vredeveldt et al., 2012). However, the evidence that eyes closed procedures benefit children in interviews is equivocal. Children who close their eyes may remember more in free recall (Experiment 1; Natali et al., 2012), but not always (Experiment 2; Mastroberardino et al., 2012). Eyes closed may benefit children when they are answering questions (Mastroberardino et al., 2012; Natali et al., 2012; and visual questions in Experiment 1), but not always (Experiment 2; and auditory questions in Experiment 1). We also note that eye closure has not always been effective in unpublished studies[1].

Given the current lack of consistent findings in the research with children we suggest caution in implying that eye closure will necessarily benefit children in police interviews. Interviews in experiments are different from forensic interviews. In an experiment the interview questions are carefully crafted and are all clearly relevant to the event being recalled. In actual interviews the questions are spontaneous, they may be ambiguous, there may be a mixture of question formats including specific, forced choice, yes/no and leading questions, and any question can be repeated multiple times in different ways and by more than one interviewer (Krähenbühl et al., 2010; Kyriakidou, 2012). In this complex context it might be the case that an eyes closed procedure would help a child cope with the difficulty of an actual interview, but this has yet to be demonstrated. A major difference between an interview in an experiment and a police interview is the number of questions. In eyes closed studies participants are asked less than 30 questions, but in a police interview children are asked an average of nearly 200 questions (Krähenbühl et al., 2010). The fact that actual interviews include so many questions means that a police interview takes a long time, well beyond the few minutes that an interview in an experiment takes. It may not be appropriate to ask children in an unfamiliar place (the interview room) with two or more unfamiliar adults (the police interviewers) to keep their eyes closed all the time. In a lengthy interview children could be asked to close their eyes only at certain times, but (as shown in Experiment 2) this may not have beneficial effects. Alternatively, if children do not spontaneously avert their gaze when answering questions in a police interview they could be advised to look away from an interviewer (Doherty-Sneddon and Phelps, 2005). But exactly what procedures would be most effective still needs to be investigated in contexts that are more similar to actual police interviews. As yet, the evidence for eye closure benefiting children's recall of events is mixed, and it may be too early to recommend such a procedure for forensic interviews.

[1]We have carried out 10 studies that have included eyes closed conditions with children. These have been as part of undergraduate or postgraduate dissertations. In each study children have been shown an unfamiliar film and/or real life event and the procedure has been the same as in Experiment 1, with children being asked for free recall and/or specific questions about the event. In only one of these other studies have we found a beneficial effect of eye closure. In the other studies there was no difference between children's performance in eyes closed and eyes open conditions. In these 9 studies children performed the same in the eyes closed and eyes open condition; there was no increase in correct responses (and no increase in incorrect responses). Therefore eyes closed did not have a detrimental effect on performance, but nor did it improve the quantity of evidence given by the children. We note these studies as a further caution to advocating eye closure as an effective technique for use with children.

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SUPPLEMENTARY MATERIAL

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REFERENCES

Clarke, C., and Milne, R. (2001). *National Evaluation of the PEACE Investigative Interviewing Course. Police Research Award Scheme Report No. PRAS/149*. London: Home Office.

Doherty-Sneddon, G. (2004). Don't look now . . . I'm trying to think. *Psychologist* 17, 82–85.

Doherty-Sneddon, G., Bonner, L., and Bruce, V. (2001). Cognitive demands of face monitoring: evidence for visuospatial overload. *Mem. Cogn.* 29, 909–919. doi: 10.3758/BF03195753

Doherty-Sneddon, G., Bonner, L., Longbotham, S, and Doyle, C. (2002). Development of gaze aversion as disengagement from visual information. *Dev. Psychol.* 38, 438–445. doi: 10.1037/0012-1649.38.3.438

Doherty-Sneddon, G., and Kent, G. (1996). Visual signals and the communication abilities of children. *J. Child Psychol. Psychiatry* 37, 949–959. doi: 10.1111/j.1469-7610.1996.tb01492.x

Doherty-Sneddon, G., Phelps, F., and Clark, J. (2007). Development of gaze over the early school years. *Br. J. Dev. Psychol.* 25, 513–526. doi: 10.1348/026151006X172018

Doherty-Sneddon, G., and Phelps, F. G. (2005). Gaze aversion: a response to cognitive or social difficulty? *Mem. Cogn.* 33, 727–733. doi: 10.3758/BF03195338

Fisher, R. P., and Geiselman, R. E. (1992). *Memory-Enhancing Techniques in Investigative Interviewing: The Cognitive Interview*. Springfield, IL: C. C. Thomas.

Ganis, G., Thompson, W. L., and Kosslyn, S. M. (2004). Brain areas underlying visual mental imagery and visual perception: an fMRI study. *Cogn. Brain Res.* 20, 226–241. doi: 10.1016/j.cogbrainres.2004.02.012

Glenberg, A. M. (1997). What memory is for. *Behav. Brain Sci.* 20, 1–19.

Glenberg, A. M., Schroeder, J. L., and Robertson, D. A. (1998). Averting gaze disengages the environment and facilitates remembering. *Mem. Cogn.* 26, 651–658. doi: 10.3758/BF03211385

Hershkowitz, I., Horowitz, D., and Lamb, M. E. (2005). Trends in children's disclosure of abuse in Israel: a national study. *Child Abuse Negl.* 29, 1203–1214. doi: 10.1016/j.chiabu.2005.04.008

Jong, A. D. (1996). Impact of child sexual abuse medical examinations on the dependency and criminal systems. *Child Abuse Negl.* 22, 645–652. doi: 10.1016/S0145-2134(98)00041-6

Krähenbühl, S. J., Blades, M., and Westcott, H. (2010). 'What else should I say?' An analysis of the question repetition practiced in police interviews of 4 to 11 year olds. *Police Pract. Res.* 11, 477–490. doi: 10.1080/15614263.2010.497346

Kyriakidou, M. (2012). *Evaluation of Children's Testimonies in the Republic of Cyprus: Implications for Criminal and Legal Procedures*. Sheffield: Sheffield University, Ph.D. thesis.

Lamb, M. E., La Rooy, D. J., Malloy, L. C., and Katz, C. (2011). *Children's Testimony: A Handbook of Psychological Research and Forensic Practice*. London: Wiley. doi: 10.1002/9781119998495

Lamb, M. E., Malloy, L. C., Hershkowitz, I., and La Rooy, D (in press). "Children and the law," in *Handbook of Child Psychology and Developmental Science, 7th Edn.,* Vol. 3, *Social, Emotional and Personality Development*, eds R. M. Lerner (General Editor) and M. E. Lamb (Volume Editor) (Hoboken, NJ: Wiley).

Mastroberardino, S., Natali, V., and Candel, I. (2012). The effect of eye closure on children's eyewitness testimonies. *Psychol. Crime Law* 18, 245–257. doi: 10.1080/10683161003801100

Ministry of Justice. (2011). *Achieving Best Evidence in Criminal Proceedings: Guidance on Interviewing Victims and Witnesses, and Guidance on Using Special Measures*. Available online at: http://www.justice.gov.uk/guidance/docs/achieving-best-evidence-criminal-proceedings.pdf

Natali, V., Marucci, F. C., and Mastroberardino, S. (2012). Long-term memory effects of eye closure on children eyewitness testimonies. *Appl. Cogn. Psychol.* 26, 730–736. doi: 10.1002/acp.2853

Perfect, T. J., Andrade, J., and Eagan, I. (2011). Eye closure reduces the cross-modal memory impairment caused by auditory distraction. *J. Exp. Psychol. Learn. Mem. Cogn.* 37, 1008–1013. doi: 10.1037/a0022930

Perfect, T. J., Andrade, J., and Syrett, L. (2012). Environmental visual distraction during retrieval affects the quality, not the quantity, of eyewitness recall. *Appl. Cogn. Psychol.* 26, 296–300. doi: 10.1002/acp.1823

Perfect, T. J., Wagstaff, G. F., Moore, D., Andrews, B., Cleveland, V., Newcombe, S., et al. (2008). How can we help witnesses to remember more? It's an (eyes)open and shut case. *Law Hum. Behav.* 32, 314–324. doi: 10.1007/s10979-007-9109-5

Phelps, F. G., Doherty-Sneddon, G., and Warnock, H. (2006). Helping children think: gaze aversion and teaching. *Br. J. Dev. Psychol.* 24, 577–588. doi: 10.1348/026151005X49872

Vredeveldt, A., Baddeley, A. D., and Hitch, G. J. (2012). The effects of eye-closure and 'ear-closure' on recall of visual and auditory aspects of a criminal event. *Eur. J. Psychol.* 8, 284–299. doi: 10.5964/ejop.v8i2.472

Vredeveldt, A., Baddeley, A. D., and Hitch, G. J. (2013). The effectiveness of eye-closure in repeated interviews. *Legal Criminol. Psychol.* doi: 10.1111/lcrp.12013. [Epub ahead of print].

Vredeveldt, A., Hitch, G. J., and Baddeley, A. D. (2011). Eyeclosure helps memory by reducing cognitive load and enhancing visualisation. *Mem. Cogn.* 39, 1253–1263. doi: 10.3758/s13421-011-0098-8

Vredeveldt, A., and Penrod, S. D. (2012). Eye-closure improves memory for a witnessed event under naturalistic conditions. *Psychol. Crime Law* 19, 893–905. doi: 10.1080/1068316X.2012.700313

Wagstaff, G. F., Brunas-Wagstaff, J., Knapton, L., Winterbottom, J., Crean, V., Cole, J., et al. (2004). Facilitating memory with hypnosis, focused meditation and eye closure. *Int. J. Clin. Exp. Hyp.* 52, 434–455. doi: 10.1080/00207140490889062

Westcott, H., and Kynan, S. (2006). Interviewer practice in investigative interviews for suspected child sexual abuse. *Psychol. Crime Law* 12, 367–382. doi: 10.1080/10683160500036962

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Effects of distraction on memory and cognition: a commentary

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This commentary is a review of the findings and ideas reported in the preceding nine articles on the effects of distraction on aspects of cognitive performance. The articles themselves deal with the disruptive effects of distraction on recall of words, objects and events, also on visual processing, category formation and other cognitive tasks. The commentary assesses the part played by "domain-general" suppression of distracting information and the "domain-specific" competition arising when tasks and distraction involve very similar material. Some forms of distraction are meaningfully relevant to the ongoing task, and Treisman's (1964) model of selective attention is invoked to provide an account of findings in this area. Finally, individual differences to vulnerability to distraction are discussed; older adults are particularly affected by distracting stimuli although the failure to repress distraction can sometimes prove beneficial to later cognitive performance.

Keywords: attention, distraction, domain-general suppression, domain-specific interference, aging

INTRODUCTION

In our noisy world distractions are almost constantly present, competing with our attention as we attempt to focus on learning, recalling past events, or solving difficult problems. What are the factors that contribute to success or failure in blocking out such distracting information? This is the principal question asked by the researchers who contributed to the preceding articles. In this commentary I will summarize some of the main findings, highlight the common principles that unite them, and try to resolve discrepancies where they exist. The commentary will be frankly biased towards my personal view of cognition in terms of active processing operations, and will draw on findings and ideas from the older literature where they appear to make sense of current observations.

DISTRACTION: GENERAL OR SPECIFIC?

One question that runs through a number of the articles is whether distraction impairs cognitive performance by depleting some general resource or by competing for specific representational space. That is, do we use up general attentional resources when we attempt to block out unwanted stimulation, thereby leaving less of a limited supply to fuel the main task, or is distraction specifically disruptive only when the irrelevant stimulation is qualitatively similar to task-relevant information? There is evidence in the foregoing articles for both positions. Mastroberardino and Vredeveldt (2014) had Italian children aged 8–11 years watch a 5 min video clip containing both visual and auditory details; the children were later asked questions about these details under various conditions. The children either watched a blank screen while doing the retrieval task, retrieved with eyes-closed (EC), watched a visual display of Hebrew words presented at a 1 s rate or heard Hebrew words spoken at a 1 s rate. The results were that the blank screen and EC conditions were associated with better recall of visual details than the visual and auditory distraction conditions which did not differ. Surprisingly, recall of auditory details was unaffected by the different retrieval conditions. The results for visual details show that both visual and auditory distraction impaired retrieval, suggesting that attentional resources were taken up in blocking the distracting stimuli, thereby reducing the effectiveness of retrieval. However, this "general" account does not fit the observed absence of an effect on recalling auditory details, and also fails to replicate the findings from an earlier study of adult participants (Vredeveldt et al., 2011) which showed modality-specific interference effects with very similar materials. The authors suggest that the present results might reflect the particular difficulty that children may have in focusing sustained attention on a retrieval task over time. This seems very reasonable although it is then curious why distraction had no effect on the recall of auditory details. The authors speculate that auditory details in the video used were tied in to accompanying social interactions and that this may have buffered retrieval against distraction.

Thus the article by Mastroberardino and Vredeveldt (2014) concludes that the recall of visual details benefits from the removal of either visual or auditory distraction. The generality of this conclusion is questioned, however, by the results of studies reported by Kyriakidou et al. (2014). These authors presented Cypriot children aged 6–12 years with a complex visual/auditory event lasting 10 min; the children were then interviewed about what they had experienced, either soon after the event or a week later. Half of the children were tested under EC conditions, and the other half were questioned about the event with their eyes open. The results showed that correct visual details were better recalled by the EC group (6.2 vs. 5.7 items). There was no significant effect of the EC manipulation on recall of correct auditory details, suggesting a modality-specific effect of distraction, but it is worth noting that the benefit to the EC group (4.9 vs. 4.3 items) was actually slightly greater than the difference between groups for visual details. It therefore seems preferable to conclude that the beneficial effect of EC during questioning was a general effect in this study although with greater benefits to the recall of visual details, as with Mastroberardino and Vredeveldt (2014).

The picture is complicated by the fact that Kyriakidou et al. (2014) found no effects of the EC manipulation in a second experiment, and indeed comment in a footnote that they have carried out 10 similar studies and found a beneficial effect of eye closure in only one case. The authors suggest that finding beneficial effects may depend on other environmental factors such as the length of the interview and how comfortable children are with the interviewer. The importance of such social factors is underlined by Buchanan et al. (2014) who had undergraduate participants trace their way mentally though a 3-D block matrix in response to auditory instructions. While performing this task, participants either closed their eyes, maintained eye contact with an interlocutor, maintained contact with the interlocutor wearing dark glasses, watched the interlocutor whose head was averted, or watched the interlocutor whose head was completely covered. Performance on the visual task was best in the EC condition, substantially reduced in the dark glasses conditions and greatly impaired in the eye contact conditions (Buchanan et al., 2014; Figure 2). This study makes the nice point that it is not simply irrelevant visual stimulations that interferes with what is essentially a visual working memory task (see e.g., Baddeley et al., 1975; Logie et al., 1990), but that the social and affective consequences of maintaining eye contact with another person are particularly disruptive to performance. Two interesting questions to pursue in this context are first whether eye contact would be equally disruptive to performance of complex auditory-verbal working memory tasks (e.g., "alpha span," Craik, 1986) and second whether the effects of eye contact are essentially due to an involuntary siphoning off of general processing resources or whether the interference is more specifically affective in nature. It should also be noted that the task used by Buchanan et al. (2014) involved online visual processing, and not the retrieval of episodic events as in the studies by Mastroberardino and Vredeveldt (2014) and by Kyriakidou et al. (2014).

Rae and Perfect (2014) studied the effects of visual distraction on the retrieval of visually presented word lists in an attempt to replicate the finding by Glenberg et al. (1998) that visual distraction reduced the retrieval of mid-list items from a recently presented list of words (Experiment 5). Participants in the Rae and Perfect (2014) experiments studied lists of individual words and then attempted to recall the words orally while looking at a screen displaying either static or dynamic visual noise (Figure 1). There was also an EC condition but the results were not reported due to a coding error in the program. In Experiment 1 the authors did find that the dynamic noise condition was associated with poorer recall of mid-list items than the static noise condition, but this result was not replicated in Experiments 2 and 3. Accordingly, Rae and Perfect express considerable doubt about the claim that environmental distraction competes with the internal resources required for effortful memory retrieval.

These doubts are at first reinforced by the results reported by Craik et al. (1996). These authors found that whereas performance of a secondary task during memory *encoding* had a large detrimental effect on the later retrieval of word lists, performance of the same secondary task during the *retrieval* phase had relatively little effect on memory performance (although performance of the secondary task was impaired). Considering that the Craik et al. (1996) study involved performance of a demanding secondary task concurrently with retrieval and yet found only slight effects on memory performance, it is not surprising that Rae and Perfect (2014) also found very small effects of a distracting visual display which needed no response from the participant. Such findings of negligible effects of competing stimuli or activities on retrieval processes are particularly puzzling in light of other data showing that retrieval operations are quite costly in terms of processing resources (Craik and McDowd, 1987; Craik et al., 1996). The best explanation may be that retrieval processing is somehow protected or given priority and that any increases in processing costs are largely borne by the secondary task or by other forms of concurrent processing.

These slight effects on retrieval must be reconsidered in light of results reported by Fernandes and Moscovitch (2000), however. These researchers had participants learn a list of auditorily presented words for later free recall. Participants also performed a variety of visually presented distracting tasks concurrently with either the encoding phase or the retrieval phase. The essential finding was that performance of a secondary task during *encoding* had a substantial negative effect on later recall regardless of the qualitative nature of the secondary task, whereas performance of a secondary task during *retrieval* was disruptive to recall only when the secondary task material was similar to the material being recalled. They concluded that during encoding the memory and concurrent tasks compete for general resources, but at retrieval the competition is for material-specific representational systems. This account is in line with Rae and Perfect's (2014) results in that little interference with recall should be expected when the distracting task (dynamic visual noise) is very different from the material being recalled (single words). By the same token it seems at first that the results of Glenberg et al. (1998) Experiment 5 are anomalous, as they did report a disruptive effect of a dynamic visual display on oral recall of words. However, the decrease in recall from the static to the dynamic display was only 0.05 (0.28–0.23) and this drop of 18% is broadly comparable to the drops of 13% reported by Fernandes and Moscovitch (2000) when participants performed a digit monitoring task during word recall, and the drop of 13% reported by Craik et al. (1996) when participants performed a visual RT task during oral word recall. It should also be noted that Wais and Gazzaley (2014, Figure 2B) report a small but significant effect of auditory distraction on the recall of visual detail, and so argue for a domain-general effect of environmental distraction on episodic retrieval. An interim summary statement might therefore be that a second source of information (either distraction or a secondary task) can disrupt retrieval, with the amount of disruption depending on such factors as the specificity of the material to be retrieved, the similarity of the secondary information to the material retrieved, the complexity or meaningfulness of the secondary information, and whether the information requires a response.

The article by Wais and Gazzaley (2014) reports a series of studies examining the effects of visual and auditory distractors on retrieval of information about visually presented objects. Two types of retrieval task were examined; in the first, participants were presented with an auditory cue word (e.g., "pumpkin") and had to decide whether the word represented a previously presented object; in the second task, participants had to recall how many exemplars of old objects had been presented in the original display (1–4). Thus the first task is a variant of cross-modal recognition memory, and the second requires detailed visual recollection. The essential results were that visual distraction reduced recognition performance whereas auditory distraction did not. Interestingly, however, both visual and auditory distraction reduced correct recall of numbers (Wais and Gazzaley, 2014; Figure 2). The authors suggest that the effect of distraction is to reduce the *fidelity* of retrieval from long-term memory (LTM), and that limited capacity control processes attempt to resolve the difference between target information and noisy interference. These resolving operations are effective when the task is relatively easy and the distracting information qualitatively different from target information (e.g., no effect of auditory distraction on recognition memory), but are overwhelmed when the task is more difficult (e.g., recall of number) so that both visual and auditory distraction are now disruptive. This result suggests that both domain-general (resource reduction) and domain-specific (interference) factors come into play in distracting tasks, with the prevalence of each depending on such factors as task difficulty and the level of specific detail required.

Other comments on the Wais and Gazzaley (2014) article include the point that there appears to be increasing interest in the concept of *fidelity* of mental representations and how fidelity may be compromised by the aging process, both during retrieval as in the present article, but also during encoding as suggested by Benjamin (2010). The authors also stress the difference between *distraction* and *interruption*. In a distraction paradigm the non-task source of stimulation is irrelevant to performance of the main task and thus should be blocked as far as possible. In an interruption paradigm the second source of information must be attended to and often responded to as well; attentional control must therefore be managed by the executive system, with attentional resources allocated to the two tasks as optimally as possible. The two paradigms are clearly different in many respects but there may also be commonalities in that disruption of the primary task will depend on such things as the amount of resource reduction caused by the secondary activity and the similarity of operations between the main task and those needed to block or perform the secondary activity. Finally, Wais and Gazzaley (2014) relate their behavioral observations of distraction to their neural underpinnings. Their data reveal that disruption of episodic retrieval of visual information is associated with the decreased efficiency of a functional network linking the left prefrontal cortex, the hippocampus and left lateral occipital cortex. This is sophisticated work helping to illuminate the complex operations involved in memory retrieval.

INTERACTIONS WITH AGING

The article by Wais and Gazzaley (2014) also reported some interesting age-related differences in the effects of distraction. First, comparisons between younger and older adults under visual distraction conditions showed no age difference in recognition performance but that younger participants outperformed older participants in recall of number. This interaction between age and type of test may be attributable to a differentially greater age decrement in recall as opposed to recognition (Craik and McDowd, 1987) or, as the authors prefer, to a greater age-related vulnerability to retrieval of details (number) as opposed to more general characteristics (overall recognition). Wais and Gazzaley (2014) also presented evidence for a greater susceptibility of older adults to distraction in a visual categorization task (Figure 5). The finding that older adults are more vulnerable to the effects of distraction has been documented in a series of studies by Hasher and Zacks (1988) and Hasher et al. (1999). One unexpected by-product of these studies is the finding that whereas older adults are less efficient than their younger counterparts at inhibiting unwanted stimulation, the irrelevant information may be used positively at a later time if the information is relevant to a new task. This beneficial effect of distraction is documented in the article by Weeks and Hasher (2014). Their general conclusion is that distraction is a "double-edged sword" for older adults. On the one hand their performance on a designated task is typically more disrupted by distraction than is the case for young adults, but on the other hand older adults can benefit from poorly inhibited distracting information if that information is then congruent to the performance of a later task. Weeks and Hasher point to a number of real-life situations in which older adults can make good use of poorly inhibited distracting stimuli, although presumably there is a trade-off between the negative effects of distraction on the first task and the benefits to a second congruent task. It also seems that the later benefits are largely attributable to *implicit* effects, and an interesting further question relates to the pattern of results when the second task requires explicit knowledge of the poorly inhibited distracting material.

ATTENTION AND DISTRACTION

Hyman et al. (2014) report two intriguing and convincing studies on inattentional blindness—the phenomenon in which preoccupied people avoid obstacles yet apparently have no perceptual awareness or later memory of these obstacles. As the authors show in an ingenious experiment, people talking or texting on cell phones avoided a low-hanging branch impeding their route yet failed to register the bizarre fact that three-dollar bills had been clipped to the branch (Hyman et al., 2014, Figure 1). The authors also point out that avoiding obstacles while distracted is typically not all-or-none: "For example, a driver needs to respond differently to a large truck, a car, a bicyclist, and a pedestrian" (Hyman et al., 2014, p. 6). They suggest that such findings may be understood in terms of the differential information provided by two distinct visual processing pathways, a ventral pathway concerned with object recognition and a dorsal pathway guiding behavior although not analyzing the perceptual nature of the information (Goodale and Milner, 1992). On the assumption that the dorsal pathway is somehow more fundamental, the results of Hyman et al. (2014) may be taken to show that distracted individuals process visual information by the dorsal route, thereby enabling avoidance of the obstacle, but not fully by the ventral route, resulting in functional "blindness" for the obstacle's characteristics.

I would like to suggest an alternative account which is that perceptual analysis is not all-or-none, but is accomplished more or less fully as a function of interactions between the salience of the perceptual input on the one hand and the person's expectations, meaningfulness of the input and amount of attention allocated to relevant processing on the other. I am appealing here to the model of selective attention proposed by Treisman (1964). This is a "levels of analysis" view in which incoming stimuli must pass through a hierarchy of analytic "tests" running progressively from analyses concerned with physical and sensory features to later analyses concerned with object identification and semantic implication. Each test level is regarded as a signal-detection decision mechanism that incoming stimuli either pass and proceed to further analytic tests, or fail and be processed no further. The level of awareness associated with a particular input depends on the number and nature of analytic levels successfully accomplished. Treisman suggested that whether or not an incoming stimulus passes each test depends both on signal strength (a d′ variable set by the incoming stimulation) and on the criterion of importance for that specific stimulus (a ß variable set by the perceiver's past history and current expectations). Thus by this view loud or bright stimuli will typically force their way through to conscious awareness, but important or expected stimuli (such as a person's name) will also reach conscious awareness even when attention is diverted, by virtue of the relevant test criteria being set favorably at all times.

This model of selective attention and its associated feature of varying levels of analysis and awareness would thus account for the results of Hyman et al. (2014) by claiming that early physical features such as shape, size, and direction were analyzed by the visual–perceptual system—enough to drive avoidance behavior—but no further analyses were either necessary or relevant, leading to a failure to identify the surprising features of the obstacle. This failure to carry out "deeper" perceptual processing would also be associated with the observed absence of later memory for features of the obstacle (Craik and Lockhart, 1972). The alert reader may have noticed that the Craik and Lockhart (1972) levels of processing model of memory was heavily influenced by Treisman's (1964) view of attention!

I believe that Treisman's general approach to how the attentional system is organized can also provide an explanation for aspects of the results reported by Scheiter et al. (2014). Their studies investigated the extent to which the provision of interesting but irrelevant information would distract individuals who were working to solve easy or difficult problems. Experiment 1 in the series showed no effects of distraction on performance given that the distracting information was entirely irrelevant to participants' task and goals. However, Experiment 2 did show an effect of distraction when participants solved easy tasks; in this experiment participants were given a pending goal for future tasks, and the distracting information was relevant to this future goal. In Treisman's terms, the pending goal would have the effect of setting favorable criteria for information relevant to the goal, thereby allowing the distracting information to be processed more fully and so consuming some portion of the individual's limited attentional resources. This effect of a pending goal (see also Goschke and Kuhl, 1993) would thus lie somewhere between the very transient effects associated with sentence contexts (e.g., "the boy leaned out of the ____") and the relatively permanent priming effects associated with stimuli such as the person's own name. To summarize this point, maintaining a pending goal may be attention consuming in its own right, but may also function by enhancing the relevance of distracting information; both factors have the potential to reduce the level of current task performance.

One other interesting result reported by Scheiter et al. (2014) was that even with a pending goal, participants performing difficult tasks were able to resist distraction whereas those performing easy tasks were not. Results on this point are mixed, however. Earlier studies by Britton et al. (1983) found that *easier* text passages occupied more cognitive capacity than difficult passages in participants who also had to carry out a sensory RT task while reading. The common theme behind the two sets of results may be the degree to which the primary task "absorbs" attention and allows the participant to lock on to the task and thereby successfully combat distraction. Greater degrees of absorption may be associated with a variety of other variables such as interest and meaningfulness.

Beaman et al. (2014) explored the effects of auditory distraction on the recognition of word pairs. Interestingly, they looked at the effects of distraction on both recognition memory and also on the quality of responses as judged by confidence ratings, the proportions of answers withheld, and the proportions of correct judgments when answers were given. The main results were that distraction had a negative effect on both the straight cognitive aspect of recognition and the metacognitive aspects of how participants managed their decision-making. In this study the distracting materials were also words, so it seems possible that participants' performance suffered both from having to block out the irrelevant distraction (a domain-general effect) and also from domain-specific effects associated with the confusion between target and distracting words. It was also the case that distraction occurred at both encoding and retrieval and this reduces somewhat the ability to analyze the locus of effects, as the authors acknowledge.

OVERVIEW AND SUMMARY

The preceding articles cover a number of aspects of the problems (and occasional benefits) associated with the effects of distraction on cognitive performance. Some articles considered the benefits of EC conditions as a way to avoid the disruptive effects of distraction, and the consensus is that closing the eyes *is* beneficial under certain conditions. Both Mastroberardino and Vredeveldt (2014) and Kyriakidou et al. (2014) found that EC conditions increased the recall of visual details, although not of auditory details; Wais and Gazzaley (2014) showed that EC was beneficial for the recognition of visual objects, and Buchanan et al. (2014) showed that EC protected against the disruptive effects of social interactions. Rae and Perfect (2014) did not find an effect of dynamic visual noise on retrieval, but perhaps because the information to be retrieved (unrelated words) was qualitatively very different from the distracting material. One clear result regarding individual differences is that older adults are more vulnerable to the effects of distraction than are their younger counterparts (Hasher and Zacks, 1988) and this result was reported by Wais and Gazzaley (2014) and by Weeks and Hasher (2014). The latter article also illustrated the interesting corollary that older adults can actually derive benefits from the poorly inhibited distracting material – under certain conditions at least. The Wais and Gazzaley (2014) article emphasized the point that distraction can result in reduced fidelity of details retrieved from LTM. The idea that reduced attentional resources are associated with a reduction in recognition memory performance, and also in the accuracy of metacognitive monitoring of retrieval, was nicely illustrated in the study by Beaman et al. (2014). The article by Hyman et al. (2014) provided dramatic illustrations of how people can avoid obstacles yet remember few details of the objects later. I pointed out how these findings can be described in terms of Treisman's (1964) "levels of analysis" view of selective attention, and suggested that Treisman's views can also be used to understand the results of Scheiter et al. (2014). The basic point here is that some stimuli may inadvertently attract attention, thereby consuming some of the limited-capacity pool, and so interfere with the top-down management of ongoing task performance. Such cases of inadvertent attraction are most likely to occur when the perceptual system is tuned to expect the distracting stimulus – either due to the current context, highly meaningful stimuli maintained over the long term, or [as in the case described by Scheiter et al. (2014)] when stimuli are relevant to a goal being maintained for some future task. If the distracting stimulation requires responses (i.e., dual-task performance), more attention will be required and more disruption will ensue. Overall then, the effects of distraction likely depend on complex interactions among such factors as the attentional demands of the distracting information, the nature of the primary task, and the similarity of operations between those required by the primary task and those required to deal with the distracting information.

REFERENCES

Baddeley, A. D., Grant, S., Wight, E., and Thomson, N. (1975). "Imagery and visual working memory," in *Attention and Performance V*, eds P. M. A. Rabbitt and S. Dornic (London: Academic Press), 205–217.

Beaman, P., Hanczakowski, M., and Jones, D. M. (2014). The effects of distraction on metacognition and metacognition on distraction: evidence from recognition memory. *Front. Psychol.* 5:439. doi: 10.3389/fpsyg.2014.00439

Benjamin, A. S. (2010). Representational explanations of "process" dissociations in recognition: the DRYAD theory of aging and memory judgments. *Psychol. Rev.* 117, 1055–1079. doi: 10.1037/a0020810

Britton, B. K., Graesser, A. C., Glynn, S. M., Hamilton, T., and Penland, M. (1983). Use of cognitive capacity in reading: effects of some context features of text. *Discourse Process.* 6, 39–57. doi: 10.1037/0022-0663.74.1.51

Buchanan, H., Markson, L., Bertrand, E., Greaves, S., Parmar, R., and Paterson, K. B. (2014). Effects of social gaze on visual-spatial imagination. *Front. Psychol.* 5:671. doi: 10.3389/fpsyg.2014.00671

Craik, F. I. M. (1986). "A functional account of age differences in memory," in *Human Memory and Cognitive Capabilities*, eds F. Klix and H. Hagendorf (Amsterdam: North-Holland), 409–422.

Craik, F. I. M., Govoni, R., Naveh-Benjamin, M., and Anderson, N. D. (1996). The effects of divided attention on encoding and retrieval processes in human memory. *J. Exp. Psychol. Gen.* 125, 159–180. doi: 10.1037/0096-3445.125.2.159

Craik, F. I. M., and Lockhart, R. S. (1972). Levels of processing: a framework for memory research. *J. Verb. Learn. Verb. Behav.* 11, 671–684. doi: 10.1016/S0022-5371(72)80001-X

Craik, F. I. M., and McDowd, J. M. (1987). Age differences in recall and recognition. *J. Exp. Psychol. Learn. Mem. Cogn.* 13, 474-479. doi: 10.1037/0278-7393.13.3.474

Fernandes, M. A., and Moscovitch, M. (2000). Divided attention and memory: evidence of substantial interference effects at retrieval and encoding. *J. Exp. Psychol. Gen.* 129, 155–176. doi: 10.1037/0096-3445.129.2.155

Glenberg, A. M., Schroeder, J. L., and Robertson, D. A. (1998). Averting the gaze disengages the environment and facilitates remembering. *Mem. Cogn.* 26, 651–658. doi: 10.3758/BF03211385

Goodale, M. A., and Milner, A. D. (1992). Separate visual pathways for perception and action. *Trends Neurosci.* 15, 20–25. doi: 10.1016/0166-2236(92) 90344-8

Goschke, T., and Kuhl, J. (1993). Representation of intentions: persisting activation in memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 19, 1211–1226. doi: 10.1037/0278-7393.19.5.1211

Hasher, L., and Zacks, R. T. (1988). "Working memory, comprehension, and aging: a review and a new view," in *The Psychology of Learning and Motivation*, Vol. 22, ed. G. H. Bower (New York: Academic Press), 193–225.

Hasher, L., Zacks, R., and May, C. (1999). "Inhibitory control, circadian arousal and age," in *Attention and Performance XVII*, eds D. Gopher and A. Koriat (Cambridge, MA: MIT Press), 653–675.

Hyman, I. E. Jr., Sarb, B. A., and Wise-Swanson, B. M. (2014). Failure to see money on a tree: inattentional blindness for objects that guided behavior. *Front. Psychol.* 5:356. doi: 10.3389/fpsyg.2014.00356

Kyriakidou, M., Blades, M., and Carroll, D. (2014). Inconsistent findings for the eyes closed effect in children: the implications for interviewing child witnesses. *Front. Psychol.* 5:448. doi: 10.3389/fpsyg.2014.00448

Logie, R. H., Zucco, G. M., and Baddeley, A. D. (1990). Interference with visual short-term memory. *Acta Psychol.* 75, 55–74. doi: 10.1016/0001-6918(90) 90066-O

Mastroberardino, S., and Vredeveldt, A. (2014). Eye-closure increases children's memory accuracy for visual material. *Front. Psychol.* 5:241. doi: 10.3389/fpsyg.2014.00241

Rae, P. J. L., and Perfect, T. J. (2014). Visual distraction during word-list retrieval does not consistently disrupt memory. *Front. Psychol.* 5:362. doi: 10.3389/fpsyg.2014.00362

Scheiter, K., Gerjets, P., and Heise, E. (2014). Distraction during learning with hypermedia: difficult tasks help to keep task goals on track. *Front. Psychol.* 5:268. doi: 10.3389/fpsyg.2014.00268

Treisman, A. M. (1964). Verbal cues, language, and meaning in selective attention. *Am. J. Psychol.* 77, 206–219. doi: 10.2307/1420127

Vredeveldt, A., Hitch, G. J., and Baddeley, A. D. (2011). Eye-closure helps memory by reducing cognitive load and enhancing visualization. *Mem. Cogn.* 39, 1253–1263. doi: 10.3758/s13421-011-0098-8

Wais, P. E., and Gazzaley, A. (2014). Distractibility during retrieval of long-term memory: domain-general interference, neural networks and increased susceptibility in normal aging. *Front. Psychol.* 5:280. doi: 10.3389/fpsyg.2014.00280

Weeks, J. C., and Hasher, L. (2014). The disruptive – and beneficial – effects of distraction on older adults' cognitive performance. *Front. Psychol.* 5:133. doi: 10.3389/fpsyg.2014.00133

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