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Working memory capacity is equally unrelated to auditory distraction by changing-state and deviant sounds

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ABSTRACT

The duplex-mechanism account states that there are two fundamentally different types of auditory distraction. The disruption by a sequence of changing auditory distractors (the changing-state effect) is attributed to the obligatory processing of the to-be-ignored information, which automatically interferes with short-term memory. The disruption by a sequence with a single deviant auditory distractor (the deviation effect), in contrast, is attributed to attentional capture. This account predicts that working memory capacity (WMC) is differentially related to the changing-state effect and to the deviation effect: The changing-state effect is assumed to be immune to cognitive control and, thus, to be unrelated to WMC. The deviation effect, in contrast, is assumed to be open to cognitive control and, thus, to be negatively related to WMC. Despite several methodological improvements over previous studies (large sample sizes, a composite measure of WMC, and a direct statistical comparison of the correlations), there was no evidence of a dissociation between the changing-state effect and the deviation effect. WMC was unrelated both to the size of the changing-state effect and to the size of the deviation effect, irrespective of whether simple stimuli (letters, Experiments 1 and 3) or complex stimuli (words and sentences, Experiment 2) were used as auditory distractors. Furthermore, a cross-experimental analysis with a total sample of $N = 601$ participants disconfirmed the idea that both types of auditory distraction show a differential relationship with WMC. Implications for models of auditory distraction are discussed.

Introduction

It is well established that task-irrelevant auditory stimuli disrupt working memory functions (Bell, Röer, & Buchner, 2013; Colle & Welsh, 1976; Ellermeier & Zimmer, 2014; Marsh, Röer, Bell, & Buchner, 2014; Schlittmeier, Hellbrück, & Klatte, 2008; Tremblay & Jones, 1998). Performance is impaired although participants are required to concentrate only on the visually presented stimuli, and are instructed to ignore all incoming auditory information. Although auditory information could, in principle, be efficiently suppressed at early stages of processing in cross-modal paradigms (Guerreiro, Murphy, & Van Gerven, 2010), there is often surprisingly substantial disruption of ongoing cognitive activities. This disruption can be seen as a failure of selective attention. Individuals with problems of controlling the contents of working memory may inadvertently process information that is irrelevant for the task at hand, which may interfere with the processing of the relevant material. However, involuntary attention switching has also been described as a vital built-in mechanism that is designed to monitor the environment for signals that are potentially relevant, and to interrupt ongoing processes once such stimuli are detected. According to the latter perspective, auditory distraction is the consequence of a system that has the delicate task of balancing out the conflicting goals of focusing on task-relevant information and remaining open for information that could be of even greater importance for the individual (e.g., the sound of a fire alarm during a written exam). In the present study, we examine the relationship between working memory capacity (WMC) and two commonly examined types of auditory distraction—distraction by changing-state sounds and distraction by deviant sounds—to gain a better understanding of the nature of these effects.

The standard paradigm for examining auditory distraction is the serial recall paradigm. A key finding in this paradigm is that the immediate serial recall of visually presented targets is impaired when auditory distractors are presented during target encoding or during a short retention interval (Buchner, Rothermund, Wentura, & Mehl, 2004; Miles, Jones, & Madden, 1991). The amount of distraction is mainly determined by the occurrence of

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abrupt changes in the to-be-ignored material and not by other potentially relevant variables such as sound level (Ellermeier & Hellbrück, 1998; Ellermeier & Zimmer, 2014). Two phenomena are often distinguished. First, the changing-state effect (Bell, Dentale, Buchner, & Mayr, 2010; Campbell, Beaman, & Berry, 2002; Jones & Macken, 1993; Jones, Madden, & Miles, 1992) refers to the observation that steady-state sequences consisting of repetitions of a single distractor item (e.g. A A A A A A A A) are less disruptive than changing-state sequences consisting of different distractor items (e.g. ABCDEFGH). Second, the deviation effect is caused by a violation of expectations that are based on regularities in the unfolding auditory stimulation (Hughes, Vachon, & Jones, 2007; Lange, 2005; Vachon, Labonté, & Marsh, 2017). Often, the deviation effect is examined by comparing steady-state sequences to deviation sequences with a single distractor item deviating from a repetitive sequence of steady-state distractors (e.g. A A A A B A A A).

At first glance, the changing-state effect and the deviation effect seem to be quite similar in that both effects essentially show that abrupt changes in the auditory modality disrupt serial recall. Therefore, it seems reasonable to assume that both phenomena can be attributed to the same underlying mechanism. Such a unitary explanation is offered by the embedded-processes model (Cowan, 1995), which attributes both the changing-state effect and the deviation effect to attentional capture. The model assumes that incoming stimuli are automatically compared against a neural model of the previous stimulation. If a mismatch is detected, attention is involuntarily oriented towards this mismatch. The changing-state effect can be elegantly explained by this model by assuming that changes in the auditory modality lead to some degree of attentional orienting away from the rehearsal of the target material. Obviously, the explanation of the deviation effect does not require any additional assumptions within this model.

Despite their similarities, it has been proposed that the changing-state effect and the deviation effect require fundamentally different explanations. According to the duplex-mechanism account (Hughes, 2014; Hughes et al., 2007), the changing-state effect results from an automatic conflict between the obligatory processing of the order of the discrete distractor items and the voluntary processing of the order of the target items. More precisely, it is assumed that incoming distractor sequences are automatically segmented into auditory objects when differences between adjacent distractors are detected. The order of these auditory objects is preattentively processed, and this processing interferes with the maintenance of the order of the to-be remembered material. The repetition of a single distractor item does not yield any order information and therefore does not interfere with order maintenance. The deviation effect, in contrast, is attributed to a different mechanism: attentional capture. The violation of an expectation is assumed to capture attention, which interferes with the encoding—but not with the retention—of the target items (Hughes, Vachon, & Jones, 2005).

At first glance, it might seem surprising that two phenomena that are superficially so similar do require so fundamentally different explanations. Indeed, it has been acknowledged even by proponents of the duplex-mechanism account that, "on the face of it, the unitary account is the more attractive given its obvious parsimony" (Hughes et al., 2007, p. 1052), but they argue that the acceptance of the duplex-mechanism account is necessitated by dissociations between the changing-state effect and the deviation effect that cannot be easily integrated into a unitary account (Hughes, Hurlstone, Marsh, Vachon, & Jones, 2013; Hughes et al., 2005, 2007; Sörqvist, 2010; for a review see Hughes, 2014). In total, these empirical arguments are seen as so compelling that the duplex-mechanism account has become the standard model for understanding auditory distraction in recent years despite being less parsimonious than a unitary model (e.g. Elliott et al., 2016; Röer, Bell, & Buchner, 2013; Schwarz et al., 2015; Sörqvist, 2010).

Nevertheless, it has been argued that a closer look at the data reveals that the empirical basis is less compelling than often assumed (e.g. Röer, Bell, & Buchner, 2014a, 2015). A recurring problem is that the arguments in favor of a dissociation of the changing-state effect and the deviation effect more often than not rely on comparisons across different experimental setups that do not allow one to compare the two phenomena directly. This is not ideal for drawing conclusions because dissociations might have been produced by methodological differences between experiments rather than by differences between the changing-state effect and the deviation effect per se (see Röer et al., 2014a, for an example). These issues suggest that more direct evidence is necessary before concluding that "the distinction at the heart of the duplex-mechanism account" is necessitated by "various functional dissociations between the impact of an auditory deviation and the changing-state effect" (Hughes, 2014, p. 32).

Here, we focus on the assumption that inter-individual differences in working memory capacity (WMC) are negatively associated with the deviation effect while they are unrelated to the changing-state effect. This dissociation has been repeatedly brought forward in favor of functionally different mechanisms underlying these two effects (e.g., Hughes, 2014). The goal of the present study is to test this hypothesis, thereby overcoming some methodological problems that could have influenced the outcomes of previous studies on this issue.

Working memory is often thought to refer to a construct that provides quick access to information that is needed for ongoing cognitive processes (Wilhelm, Hildebrandt, & Oberauer, 2013). Accordingly, working memory capacity is thought to reflect inter-individual differences in the limited capacity of a person's working memory, that is, in the amount of information individuals have available for ongoing cognitive processes. Most tasks therefore require participants to store information over a short period of time while performing other cognitive activities such as solving arithmetic problems or reading sentences (Lewandowsky, Oberauer, Yang, & Ecker, 2010; Oswald, McAbee, Redick, & Hambrick, 2014; Redick et al., 2012). For example, in a typical complex-span task such as the operation span task (Turner & Engle, 1989), participants have to evaluate the correctness of mathematical equations, each followed by the presentation of a word. After having responded to a set of these equations, the participants are prompted to recall the presented words in their correct order.

There are different theoretical views on what underlies individual differences in WMC. For example, it has been suggested that inter-individual differences in WMC largely reflect the capacity with which memory processes such as rehearsal, maintenance, updating and controlled search can be carried out (Unsworth & Engle, 2007) or, alternatively, the efficiency with which short-term memory bindings (such as the binding of an item to its list position) can be formed and maintained (Wilhelm et al., 2013). According to the executive-attention view (Engle, 2002), WMC measures the individual ability to use cognitive control to focus attention on maintaining information in working memory while avoiding distraction by concurrent cognitive activities. This theoretical view is mainly based on findings showing that WMC predicts performance in tasks that require executive control such as the Stroop task or the dichotic-listening task (Conway, Cowan, & Bunting, 2001; Engle, 2002; Kane, Bleckley, Conway, & Engle, 2001), and is therefore often used in the irrelevant-sound literature to justify the prediction that persons with high WMC should be less distracted by attention-grabbing sound than persons with low WMC (Elliott & Cowan, 2005; Hughes, 2014; Hughes et al., 2013; Sörqvist, 2010). However, it is sensible to note that the view that high WMC is associated with a greater ability to resist interfer-