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Differential effects of cue-based and sequence knowledge-based predictability on multitasking performance☆

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ABSTRACT

Everyday multitasking often is characterized by predictable sequences. While such sequential regularities are present in setups using the Serial Reaction Time Task (SRTT), many laboratory studies on dual-tasking performance use random sequences of stimuli in either of the two tasks. In the current study, following single-task training on the SRTT, participants completed trials where they were confronted with an additional visual-manual task with either a random (Experiment 1) or a partially predictable (Experiment 2) stimulus sequence. In the SRTT, we cued participants with respect to which of the four stimulus options were yet to occur (before a new round with all four options would start). We randomly mixed a sequence to be practiced with random sequences of the same length and with the same constraint. Thus, we were able to vary predictability of upcoming stimuli (from chance to 100%) as well as sequence knowledge (practiced vs. random sequence) in order to assess how cueing and sequence knowledge, as two potential bases of prediction, would affect performance in single- and dual-tasking. Results suggest that both cueing and sequence knowledge-based prediction can lead to shorter RTs in dual-tasking. In previous studies, the disruption of sequence learning by adding a task with a random stimulus sequence has been linked to the effects of automatic prediction between events in the two tasks. In line with these studies, dual-task performance did not impede usage of sequence knowledge when a task with a predictable (rather than random) sequence of stimuli was added to the SRTT.

1. Introduction

Although limits to multitasking performance have been linked to limits in simultaneous response selection (e.g., Pashler, 1994; see Koch, Poljac, Müller, & Kiesel, 2018, for a recent review), relatively little research has investigated how predictability can support multitasking (cf. Broeker et al., 2017). One aspect, namely temporal predictability of when a stimulus will be presented, has been discussed by Pashler (1994) when referring to psychological refractory period (PRP) effects in the special case of simple reaction time (RT). The aspect we focus on in this study is the predictability of which stimulus and response will occur next. Putatively, advance information about upcoming stimuli and responses could lead to advance preparedness, avoiding bottlenecks (e.g., Luria & Meiran, 2003), or reduce crosstalk by minimizing simultaneous processing of overlapping information (cf. Koch, 2009).

While in many dual-task experiments in the lab, the sequence of stimuli and responses in either task is random, this is arguably rarely the case in everyday life, where tasks (such as cooking and talking) contain sequential regularities that are learned and used to sustain performance (Botvinick & Bylsma, 2005; Schiffer, Waszak, & Yeung, 2015). Such sequential regularities can be based on fixed sequences that can be stored in long-term memory. Moreover, the amount of potential upcoming processing can be reduced by cues (e.g., water boiling) and can be constrained by the options left (e.g., the more ingredients are already in the soup, the fewer remain to choose from). Here we explore whether and how (a) sequence knowledge and (b) such local cued constraints in remaining options are used in dual-tasking as two different potential sources of prediction and advance preparation (cf.

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Broeker et al., 2017).

1.1. Structural properties of the serial reaction time task leading to different sources of predictability

Many studies on sequence learning use the Serial Reaction Time Task (SRTT; Nissen & Bullemer, 1987; for reviews see e.g. Abrahamse, Jiménez, Verwey, & Clegg, 2010; Schwarb & Schumacher, 2012). In a typical setup, the participants receive choice reaction instructions for four target locations on the screen, compatibly mapped to response keys, and are to press the key matching the current stimulus position as quickly as possible. While performing this task, they acquire knowledge about sequential regularities in the stimuli and responses. This sequence knowledge can be operationalized in form of shorter response times (RT) to the repeating sequence, as compared to non-practiced sequences (cf. Vaquero, Jiménez, & Lupiáñez, 2006).

In our study, we compared such sequence knowledge with cued local constraints as two sources of preparation of stimulus- or response processing. This relates to a methodological issue due to the structural properties of the sequences used in research with the SRTT that has received little attention in work on sequence learning so far: Take, for example, a second order conditional sequence, such as 3–4–2–3–1–2–1–4–3–2–4–1, used in many SRTT experiments (e.g., Schumacher & Schwarb, 2009; Shanks, Wilkinson, & Channon, 2003; Wilkinson & Shanks, 2004). The sequence is called second order conditional, because each stimulus occurs with all possible predecessors (e.g., 1 is preceded by 3, by 2, and by 4, at different positions in the sequence). If exclusively relying on the current stimulus (i.e., first order), predictions concerning the next stimulus are at chance level. Yet, the next stimulus can be predicted successfully, if the current and the preceding stimulus (i.e., second order) are taken into account together. Accordingly, authors suggest (cf. Shanks et al., 2003; Vaquero et al., 2006) that participants have to use the current trial and the preceding one in order to predict the current stimulus. Yet, other structural properties might be exploited as well: The events can be grouped in such a way that each of the four stimuli and responses has to occur before any of the events are repeated (e.g., by choosing a different starting point, such a package structure is apparent in the above sequence: 4–2–3–1 2–1–4–3 2–4–1–3). Thus, the last event in a quadruple is perfectly predictable. From our work with the SRTT (Stahl, Barth, & Haider, 2015), we know that participants can learn such regularities incidentally.

Vaquero et al. (2006) explained that the typical practice of assessing sequence knowledge by comparing RTs on (a) trials with the practiced sequence with (b) the supposedly longer RTs on randomly sequenced trials is flawed, because random material can be expected to contain more trials in which the stimulus repeats after two trials than is the case in the regular sequence. Thus, the larger proportion of trials with RT costs due to inhibition of return (e.g., Klein, 2000; Mayr, 2009) in the randomly sequenced material as compared to the fixed-sequence material confounds the assessment of sequence knowledge. Instead, Vaquero et al. (2006) suggested using the RT difference between the practiced and an alternative sequence as a measure of sequence knowledge. This balances the proportion of trials potentially affected by inhibition of return. In addition, both the practiced and the unpracticed sequence can feature the local constraint that each stimulus (and response) in a quadruple must be presented once, before any of the events repeat. Thus, the RT measure of sequence knowledge is not confounded by differences with respect to the local repetition constraints (as this constraint can be satisfied in the practiced and the unpracticed sequence alike). Yet, we lack knowledge about the extent to which people use such local constraints for preparing for upcoming events in a choice reaction task. In the current work, we follow up on this perspective and make the local repetition constraints more obvious, both in the fixed-sequence material and in the material generated by random draws (yet without replacement). This method for generating random material avoids the confounders present in trials affected by inhibition of return (see Vaquero et al., 2006).

Taken together, the work above suggests that the SRTT performance can reflect long-term memory based sequence knowledge as well as local constraints. By assessing the reduction of RT with increasing predictability within a quadruple (local repetition constraint-based), we test the extent to which the participants make use of this source of predictability in single and dual-tasking.

1.2. Effects of predictability on the serial reaction time task in dual-tasking

Past research with single-task setups suggests that participants use cues as well as additional information (i.e., frequency of stimuli or conditions) to prepare for the upcoming trial (cf. Gaschler, Schwager, Umbach, Frensch, & Schubert, 2014, for an overview). Yet, sequence knowledge and cueing as sources of predictability have been treated separately so far, and work on the impact of either source of predictability on dual-task performance is lacking. Also, we lack knowledge with respect to whether sequence knowledge still plays out when there are such cued constraints. In past studies with the SRTT, participants were not cued with respect to what stimulus positions were remaining for the upcoming trial(s).

Cueing can lead to pre-activation of stimulus representations, such that stimuli can be processed faster and actions can be selected more quickly, because the respective thresholds can be reached faster (cf. Mattler, 2005; Waszak, Cardoso-Leite, & Hughes, 2012). Yet, in their review, Waszak and colleagues furthermore concluded that predictions can come at the cost of difficulties in distinguishing predicted from presented stimuli. Furthermore, Astor-Jack and Haggard (2005) showed costs when an action about to be initiated was in addition demanded by a stimulus. It is thus not a given fact that the combination of two sources of predictability has to have a positive effect on performance.

There can be different perspectives with respect to how dual-tasking (introduced after sequence knowledge has already been acquired) should affect the usage of sequence knowledge and of cued local constraints. On the one hand, one can expect that the effects of predictability on performance are larger in dual- as compared to single-tasking: Performance in choice reaction tasks might be characterized by very low RTs that are hard to reduce further by predictability. Yet increasing the RT level by dual-tasking might make room for predictability-based reduction of RT. In a similar vein, sequence knowledge has been shown to increase performance in tasks in which control demands originate from added irrelevant distracting information, reducing the Stroop effect (Haider, Eichler, & Lange, 2011), the Simon effect (Koch, 2007; Tubau & López-Moliner, 2004), and the impact of biased transition frequencies (Tubau, Hommel, & López-Moliner, 2007). Therefore, a beneficial impact of sequence knowledge can also be expected when control demands originate from dual-tasking (where the information is relevant to one or the other task, rather than relevant vs. irrelevant information).

On the other hand, bottlenecks have been proposed not only with respect to response selection (Pashler, 1994; Schumacher & Schwarb, 2009), but also with respect to attentional orienting (Janczyk & Berryhill, 2014), item selection in working memory (Janczyk, 2017), visual encoding (Jolicoeur, 1999), or memory retrieval (cf. Riby, Perfect, & Stollery, 2004), processes that might be relevant for accessing sequence knowledge in long-term memory or for using cues and local repetition constraints. It is thus conceivable that participants in dual-tasking, compared with single-tasking, are in a worse position to retrieve sequence knowledge and make use of cues and local repetition constraints. This would be in line with work documenting that participants can acquire sequence knowledge under secondary task demands, yet sequence knowledge only influences RT once the secondary task does not have to be performed any longer (Frensch, Lin, & Buchner, 1998; Frensch, Wenke, & Rünger, 1999). Thus, random sequencing in a