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Effects of rule uncertainty on cognitive flexibility in a card-sorting paradigm

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ABSTRACT

Cognitive flexibility has been studied in two separate research traditions. Neuropsychologists typically rely on rather complex assessment tools such as the Wisconsin Card Sorting Test (WCST). In contrast, task-switching paradigms are used in experimental psychology to obtain more specific measures of cognitive flexibility. We aim to contribute to the integration of these research traditions by examining the role of the key factor that differs between the WCST and experimental task-switching paradigms: rule uncertainty. In two experimental studies, we manipulated the degree of rule uncertainty after rule switches in a computerized version of the WCST. Across a variety of task parameters, reducing rule uncertainty consistently impaired the speed and accuracy of responses when the rule designated to be more likely turned out to be incorrect. Other performance measures such as the number of perseverative errors were not significantly affected by rule uncertainty. We conclude that a fine-grained analysis of WCST performance can dissociate behavioural indicators that are affected vs. unaffected by rule uncertainty. By this means, it is possible to integrate WCST results and findings obtained from task-switching paradigms that do not involve rule uncertainty.

1. Introduction

Cognitive flexibility allows for the efficient adaptation of goal-directed behaviour to changing environmental demands (Garcia-Garcia, Barcelo, Clemente, & Escera, 2010) and has thus been proposed to be a core component of executive functioning (Miyake et al., 2000). The construct of cognitive flexibility has attracted interest from both neuropsychologists and researchers in the field of experimental psychology.

Neuropsychologists typically rely on rather complex assessment tools such as the Wisconsin Card Sorting Test (WCST, Berg, 1948; Grant & Berg, 1948; Heaton, Chelune, Talley, Kay, & Curtiss, 1993) to study cognitive flexibility in clinical populations. The WCST requires participants to sort cards and to use the experimenter's feedback to shift between different sorting rules. Individuals with damage to the frontal lobes (Demakis, 2003; Milner, 1963) or to the basal ganglia (Eslinger & Grattan, 1993) as well as patients with a variety of neurological and psychiatric diseases (Kudlicka, Clare, & Hindle, 2011; Lange, Brückner, Knebel, Seer, & Kopp, in press; Lange, Seer, et al., 2016; Lange, Vogts, et al., 2016; Roberts, Tchanturia, Stahl, Southgate, & Treasure, 2007; Romine et al., 2004; Shin, Lee, Kim, & Kwon, 2014; Snyder, 2013) have been shown to have considerable difficulties with the task demands associated with the WCST. However, the interpretation of these findings is complicated by the task impurity of the WCST (Miyake & Friedman, 2012; Strauss, Sherman, & Spreen, 2006). As the WCST confounds a variety of different cognitive processes (Dehaene & Changeux, 1991; Ridderinkhof, Span, & Van Der Molen, 2002), WCST performance deficits cannot unequivocally be attributed to impaired cognitive flexibility (Cools, Barker, Sahakian, & Robbins, 2001).

Avoiding the complexity issues associated with the WCST, experimental psychologists have developed variants of the task-switching paradigm as a more process-pure alternative for the study of cognitive flexibility (Allport, Styles, & Hsieh, 1994; Rogers & Monsell, 1995). These paradigms involve switching between different mental operations (e.g., indicating whether a number is smaller or larger than five vs. indicating whether a number is odd or even) after a fixed number of task repetitions (alternating-runs paradigm), in response to task cues (task-cuing paradigm), or at the discretion of the participant (voluntary task switching). Research using task-switching paradigms has revealed a wide range of insights into the mechanisms contributing to cognitive flexibility in the healthy mind (Grange & Houghton, 2014; Kiesel et al., 2010; Monsell, 2003; Vandierendonck, Liefooghe, & Verbruggen, 2010).

Unfortunately, although clinical neuropsychology and experimental psychology share their interest in the concept of cognitive flexibility,

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these two research traditions have remained largely unintegrated. The few studies that have attempted integration focused on the commonalities between the WCST and task-switching paradigms on the performance level (Gamboz, Borella, & Brandimonte, 2009; Miyake et al., 2000) or on level of neural activation (Buchsbaum, Greer, Chang, & Berman, 2005). Here, we adopt a different approach to bridging the two literatures by examining those task characteristics that differ between the WCST and experimental task-switching paradigms.

We argue that the critical factor distinguishing the WCST from the majority of task-switching paradigms is rule uncertainty. Both the WCST and task-switching paradigms require participants to apply one task rule on some trials (e.g., match cards by colour; categorize numbers based on magnitude) and to apply a different task rule on other trials (e.g., match cards by shape; categorize numbers based on parity). However, in contrast to task-switching paradigms, the WCST involves two important characteristics whose combination entails that participants cannot always be certain about the currently valid task rule. First, examinees performing the WCST have to shift between three different task rules (i.e., matching cards according to colour, shape, or number), whereas most task-switching paradigms involve only two viable rules. Second, changes of the valid WCST rule are communicated via implicit transition cues (i.e., the examinee is informed that the applied sorting rule is not correct and thus needs to be changed), which do not specify the rule to which participants should switch. In contrast, most cued task-switching paradigms use task cues, which explicitly state the rule that should be applied on the upcoming trial. While several task-switching studies have used more than two task rules (Buchler, Hoyer, & Cerella, 2008; Emerson & Miyake, 2003; Kessler & Meiran, 2010; Kleinsorge & Apitzsch, 2012; Kleinsorge & Scheil, 2015; Kray, Li, & Lindenberger, 2002; Rubin & Meiran, 2005; Souza, Oberauer, Gade, & Druey, 2012) or transition-cuing procedures (Chevalier, Wiebe, Huber, & Espy, 2011; Forstmann, Brass, Koch, & von Cramon, 2005; Reuss, Kiesel, Kunde, & Hommel, 2011; Saeki & Saito, 2009; Schneider & Logan, 2007; Van Loy, Liefooghe, & Vandierendonck, 2010; West, Langley, & Bailey, 2011) in the past, it is only the combination of these two characteristics that gives rise to rule uncertainty on the WCST (Kopp & Lange, 2013). When being cued to switch away from an incorrect rule on the WCST, examinees do not have any information as to which of the remaining two rules might be the correct one. This uncertainty about the correct rule may affect the cognitive processes that allow switching from one rule to another (Barceló, Escera, Corral, & Periáñez, 2006; Barceló, Periáñez, & Nyhus, 2008; Kopp & Lange, 2013; Lange, Seer, Finke, Dengler, & Kopp, 2015).

To integrate the neuropsychological literature using the WCST and the experimental literature using task-switching paradigms, it is thus necessary to understand the contributions of rule uncertainty to WCST performance. One possibility to manipulate the degree of rule uncertainty associated with rule switches on the WCST involves varying the number of WCST rules (Kopp & Lange, 2013; Lange, Kröger, et al., 2016; Lange, Lange, et al., 2016). However, by changing the number of rules one does not only manipulate rule uncertainty but also confounded factors such as working memory load or the need for concept learning. Here, we present an alternative manipulation that allows examining which aspects of WCST performance are affected by rule uncertainty.

In a recent study using a computerized version of the WCST (the cWCST), we (Lange, Seer, Müller, & Kopp, 2015) informed participants that one of the three standard WCST rules was more frequent than the other two rules. This global information about rule frequencies allowed participants to know that, after a switch away from the more frequent rule, the remaining two rules were equally likely to be correct (high rule uncertainty). In contrast, after a switch away from one of the two less frequent rules, the more frequent rule was more likely to be correct (i.e., in 70% of the trials) than the alternative rule (low rule uncertainty). Although our previous study focused on the psychophysiological correlates of rule uncertainty on the cWCST, the associated behavioural data already provided some insights into the uncertainty-related differences between the WCST and task-switching paradigms.

First, as compared to situations with reduced rule uncertainty, switching to a rule in the high-uncertainty condition was associated with a considerable increase in response latencies. Because of the chosen conditional probabilities, not all rule switches resulted directly in the correct identification of the valid task rule. On a subset of trials, participants were informed that they had selected the wrong rule and thus that they had to perform an additional switch to get to the currently valid rule. We referred to these trials as *addendum switch trials*. Participants were faster and more accurate in switching to the valid rule on the addendum switch trial in the high-uncertainty condition as opposed to the low-uncertainty condition. In other words, reducing the rule uncertainty that is typically associated with the WCST accelerated responses on switch trials, but decelerated addendum switches when the rule chosen on the switch trial proved to be invalid. Reduced rule uncertainty might thus induce an increased commitment to the more likely rule on the switch trial which has to be overcome at the expense of increased performance cost on the addendum switch trial. In contrast, some cWCST counterparts of traditional WCST measures (such as the number of perseverative errors or the number of set-loss errors) did not seem to be affected by our manipulation of rule uncertainty.

The aim of the present studies was threefold. First, we wanted to replicate the behavioural evidence for rule-uncertainty effects on the cWCST presented by Lange, Seer, Müller, et al. (2015). Second, we aimed at testing potential moderators and boundary conditions of these effects, which might be of particular interest to experimental psychologists studying cognitive flexibility using task-switching paradigms. Third, we increased our focus on traditional WCST measures to highlight the implications of rule-uncertainty effects for the interpretation of neuropsychological WCST data.

2. Study 1

Study 1 was designed to replicate and extend the results of Lange, Seer, Müller, et al. (2015). Specifically, we aimed at a more detailed understanding of rule-uncertainty effects on cWCST performance by examining the role of two potential moderators. On the one hand, we manipulated the likelihood of the more likely rule in low-uncertainty conditions. While this likelihood was set to a constant 70% in our previous study (Lange, Seer, Müller, et al., 2015), it varied block-wise between 60% and 80% in Study 1. By means of this manipulation, we explored whether larger reductions of rule uncertainty lead to larger effects on cWCST performance. Stronger rule-uncertainty effects in the 80% condition would indicate that participants use the globally provided numeric likelihoods to differentially commit to the more likely rule on switch trial. On the other hand, we manipulated the amount of preparation time given to participants between the onset of feedback cues and the onset of target displays (i.e., the cue-target interval, CTI). It is commonly assumed that, at long CTIs, some of the processes that are required to execute a switch from one rule to another can already be completed before target onset (Kiesel et al., 2010). This preparatory component of switching is often linked to active processes of task-set reconfiguration. In contrast, passive processes of task-set inertia have been proposed to account for the residual component of switching, that is, the component that is unaffected by CTI length (Meiran, 2000). Analysing the potential effect of CTI length on rule-uncertainty effects in the cWCST might thus reveal which kind of processes (active task-set reconfiguration vs. passive task-set inertia) is affected by rule uncertainty.

2.1. Methods

2.1.1. Participants

Twenty-five university students (18 female; 7 male; mean age = 22.16 years, SD = 3.59 years) with normal or corrected-to-