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Cognitive persistence: Development and validation of a novel measure from the Wisconsin Card Sorting Test

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A B S T R A C T

The Wisconsin Card Sorting Test (WCST) has long been used as a neuropsychological assessment of executive function abilities, in particular, cognitive flexibility or "set-shifting". Recent advances in scoring the task have helped to isolate specific WCST performance metrics that index set-shifting abilities and have improved our understanding of how prefrontal and parietal cortex contribute to set-shifting. We present evidence that the ability to overcome task difficulty to achieve a goal, or "cognitive persistence", is another important prefrontal function that is characterized by the WCST and that can be differentiated from efficient set-shifting. This novel measure of cognitive persistence was developed using the WCST-64 in an adult lifespan sample of 230 participants. The measure was validated using individual variation in cingulo-opercular cortex function in a subsample of older adults who had completed a challenging speech recognition in noise fMRI task. Specifically, older adults with higher cognitive persistence were more likely to demonstrate word recognition benefit from cingulo-opercular activity. The WCST-derived cognitive persistence measure can be used to disentangle neural processes involved in set-shifting from those involved in persistence.

1. Introduction

Psychologists have long recognized that achievement on goal-directed tasks emerges not only as a result of cognitive or intellectual ability, but also from the motivation, drive, or will to succeed (Wechsler, 1950). Thus, "persistence"—applying effort to overcome a mental challenge—is thought to be an essential component underlying performance on cognitive tasks. However, the contribution of persistence to inter-individual variability in performance on mentally-demanding tasks is often neglected. This may be due, in part, to the paucity of neuropsychological assessments that disentangle the effects of persistence and cognitive ability on performance.

Existing measures of persistence and related motivational factors typically take the form of subjective self-report or observer-report surveys that may be biased by prior knowledge of achievement (Choi et al., 2010; Cloninger et al., 1994; Doherty-Bigara and Gilmore, 2016; Onatsu-Arvilommi and Nurmi, 2000; Pintrich et al., 1991, 1993; Steinberg et al., 2007) and are often domain-specific (e.g., academic achievement; Onatsu-Arvilommi and Nurmi, 2000; Pintrich et al., 1991, 1993; Zhang et al., 2011). Of the few behavioral measures of persistence, most examine time spent on challenging tasks before deciding to quit (for review, see Leyro et al., 2010). While persistent individuals may be likely to engage effort in task performance for longer periods, the reverse does not follow, as higher ability levels may also increase how long individuals choose to work on a task. The goal of the current study was to establish a behavioral measure of persistence that was independent of task ability and reflected the application of effort to overcome performance difficulty, using the Wisconsin Card Sorting Task (WCST).

The WCST is a commonly used neuropsychological assessment that was developed to characterize frontal lobe function (Drewe, 1974; Milner, 1963; Nelson, 1976). The standard version of the task (Grant and Berg, 1948; Heaton, 1981; Kongs et al., 2000; Milner, 1963) involves matching a target card to one of four sample cards that vary in color, shape, and number, without knowing a priori how to match the cards. Participants learn the sorting rule (color, shape, or number) through trial-and-error from feedback on each trial, and the rule is changed after 10 consecutive correct responses.

The traditional index of frontal lobe function on the WCST is perseverative errors, that is, the number of errors made because participants sorted a card based on the previously reinforced rule instead of the current rule. The prefrontal cortex is thought to be essential for flexible rule switching, or "set-shifting", because patients with lateral and/or dorsomedial prefrontal lesions exhibit more perseverative errors on the WCST than healthy controls or patients with non-frontal damage (Barceló and Knight, 2002; Drewe, 1974; Milner, 1963; Nelson, 1976;

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Stuss et al., 2000). Additionally, rule switches during the WCST and similar tasks elicit activity in lateral and dorsomedial prefrontal cortex (Hampshire et al., 2008; Konishi et al., 2002, 1998; Nagahama et al., 1998; Ravizza and Carter, 2008), suggesting that these regions support set-shifting. However, non-prefrontal regions including posterior parietal cortex, occipital cortex and the striatum have also been implicated in set-shifting (Dang et al., 2012; Graham et al., 2009; Konishi et al., 2002, 1998; Nagahama et al., 1998; Ravizza and Carter, 2008; Wang et al., 2015). Moreover, patients with prefrontal lesions can exhibit deficits in non-perseverative errors in addition to perseverative errors (Barceló and Knight, 2002; Drewe, 1974). These findings call into question the specificity of prefrontal cortex function in set-shifting, and appear to reflect the multi-faceted nature of cognitive processes that support WCST performance. The WCST requires not only set-shifting to flexibly switch rules, but also problem solving to deduce the correct sorting rule and working memory to maintain and retrieve task goals.

Due to its varied behavioral demands, neuroimaging and patient studies find that the WCST actually engages widespread prefrontal, parietal and occipital regions (Berman et al., 1995; Konishi et al., 2002, 1998; Nagahama et al., 1998; Nyhus and Barcelo, 2009). Recent research has attempted to specify the contributions of distinct cortical areas to WCST performance by breaking down the task into its constituent components or manipulating task demands (Barceló, 1999; Barceló and Knight, 2002; Dang et al., 2012; Graham et al., 2009; Lange et al., 2016; Nyhus and Barcelo, 2009; Ravizza and Carter, 2008; Stuss et al., 2000; Wang et al., 2015). In particular, Barceló (1999, 2003) and Barceló and Knight (2002) introduced the concept of an "efficient error", which occurs when a participant happens to switch to the wrong sorting rule after receiving feedback that the rule has changed. A participant who is performing optimally is expected to commit efficient errors on 50% of trials following the detection of a rule change, because there are two remaining rules that could possibly be correct (see Fig. 1). Importantly, when efficient errors were coded separately, patients with prefrontal lesions made fewer efficient errors, more perseverative errors, and more non-perseverative errors compared to controls (Barceló and Knight, 2002). These results suggest a dissociation between efficient errors and other error types, wherein prefrontal damage increases perseverative and non-perseverative errors while selectively decreasing efficient errors. Indeed, a factor analysis of error types on the WCST confirmed this distinction: efficient errors were negatively correlated with all other error types, whereas perseverative and non-perseverative errors were strongly positively correlated and did not load onto separate factors (Godinez et al., 2012). Because efficient errors reflect optimal shifting processes whereas other errors indicate suboptimal shifting, scoring efficient and non-perseverative errors together likely obscured the effects of frontal damage in prior studies (Drewe, 1974; Milner, 1963; Nelson, 1976; Stuss et al., 2000).

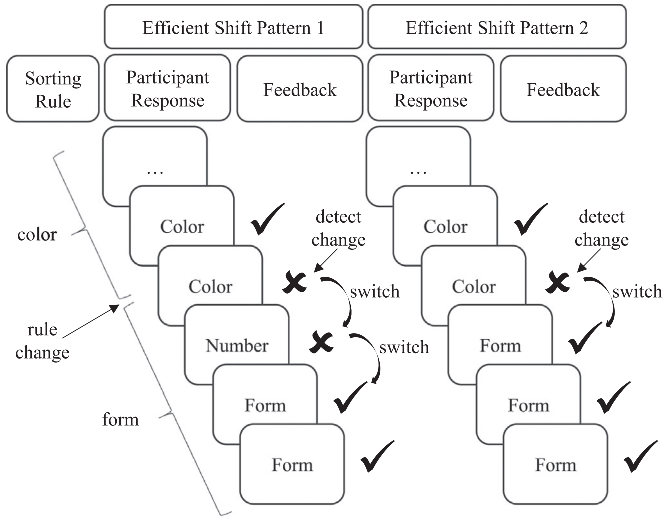

Fig. 1. Diagram of two possible efficient shift trial sequences in which the correct sorting rule changed from color to form. ✓: correct response; ✗: incorrect response. Participants can first detect a rule change upon receiving negative feedback for using the previous sorting rule. Following detection of a rule change, participants performing optimally will switch to one of the two remaining rules, which could be the incorrect rule (Efficient Shift Pattern 1) or the correct rule (Efficient Shift Pattern 2). An efficient error occurs when the participant switches to the wrong rule but then switches to and keeps using the right rule (e.g., the "Number" response in Efficient Shift Pattern 1). Both patterns shown in the diagram are expected as part of the optimal performance strategy after the sorting rule changes.

Clearly defining efficient errors and recognizing that they index normal and adaptive shifting processes has enabled targeted investigation of the neural correlates of set-shifting. Research using event-related potentials has shown that efficient errors elicit larger parietal-occipital N1 and frontal P2 amplitudes than perseverative errors (Barceló, 1999), suggesting that set-shifting involves visual attention and frontal control. Relative to rule maintenance trials, switching rules evokes a robust frontal P3a component (Barceló, 2003) that is modulated by uncertainty of decision-response outcomes (Kopp and Lange, 2013). Efficient shifting in healthy young adults engages left precuneus, left inferior frontal gyrus (IFG), right dorsal anterior cingulate cortex (dACC) and right middle frontal gyrus (MFG) compared to correctly repeating a rule (Lao-Kaim et al., 2015). In addition, parametrically increasing rule search demands elicits greater activity in the bilateral IFG and MFG, bilateral inferior parietal lobe, right angular gyrus, superior parietal lobule, precuneus and putamen (Wang et al., 2015). Thus, successful set-shifting recruits a composite network of lateral and medial prefrontal cortex and posterior parietal cortex.

While our understanding of the specific neural networks involved in successful set-shifting on the WCST has advanced, other cognitive processes important to WCST performance have received less attention. In particular, WCST performance depends not only on the ability to flexibly shift between sorting rules, but also on the continued willingness to search for and apply the correct rule after encountering negative feedback that inevitably occurs following a rule switch. In other words, individuals have to apply effort to overcome the performance difficulty that arises from switching rules, or use cognitive persistence, in order to respond correctly. The present study leverages the Barceló and Knight (2002) approach to isolate a cognitive persistence component of WCST performance and relate it to a prefrontal neural signature of persistence. Specifically, cognitive persistence was related to activity in a cingulo-opercular network that responds to performance difficulty and subsequently leads to better performance during a challenging speech recognition in noise task (Eckert et al., 2016; Vaden et al., 2015, 2016, 2013).

Although the role of cognitive persistence in WCST performance has not been explicitly studied, there is some evidence that it may be important. Reports from studies of patients with prefrontal lesions suggest that receiving frequent negative feedback during WCST administration caused some patients to become so frustrated that they refused to complete the task (Drewe, 1974; Nelson, 1976). The decision to quit a challenging task has previously been used as an inverse measure of persistence (Daughters et al., 2005a, 2005b, 2005c; Leyro et al., 2010; Quinn et al., 1996; Steinberg et al., 2010, 2012; Ventura et al., 2013). Choosing to terminate the WCST represents an extreme and relatively rare consequence of low persistence, but persistence may still affect performance among those who complete the task. Indeed, ratings of task effort on an intrinsic motivation survey (Choi et al., 2010) predicted overall WCST performance in patients with schizophrenia (Tas et al., 2012). Additionally, depressive symptoms, which often occur with decreased motivation and persistence (Potter et al., 2007; Ravizza and Delgado, 2014), predicted the total number of WCST errors made by adolescents (Han et al., 2016).

The importance of cognitive persistence becomes apparent when considering two hypothetical individuals who have equal difficulty with set-shifting, but differ in persistence. By definition, task difficulty