Acta Psychologica 191 (2018) 124–130

Contents lists available at ScienceDirect

Acta Psychologica

journal homepage: www.elsevier.com/locate/actpsy

# Disentangling cognitive from motor control: Influence of response modality on updating, inhibiting, and shifting

Marpessa Rietbergen[a,b,c,*], Ardi Roelofs[a], Hanneke den Ouden[a], Roshan Cools[b]

[a] Radboud University, Donders Institute for Brain, Cognition and Behaviour, Centre for Cognition, Montessorilaan 3, 6525 HR, Nijmegen, the Netherlands
[b] Radboud University, Donders Institute for Brain, Cognition and Behaviour, Centre for Cognitive Neuroimaging, Kapittelweg 9, 6525 EN, Nijmegen, the Netherlands
[c] International Max Planck Research School for Language Sciences, Wundtlaan 1, 6525 XD, Nijmegen, the Netherlands

ARTICLE INFO

*Keywords:*
Cognitive control
Motor control
Response modality

ABSTRACT

It is unclear whether cognitive and motor control are parallel and interactive or serial and independent processes. According to one view, cognitive control refers to a set of modality-nonspecific processes that act on supramodal representations and precede response modality-specific motor processes. An alternative view is that cognitive control represents a set of modality-specific operations that act directly on motor-related representations, implying dependence of cognitive control on motor control. Here, we examined the influence of response modality (vocal vs. manual) on three well-established subcomponent processes of cognitive control: shifting, inhibiting, and updating. We observed effects of all subcomponent processes in reaction times. The magnitude of these effects did not differ between response modalities for shifting and inhibiting, in line with a serial, supramodal view. However, the magnitude of the updating effect differed between modalities, in line with an interactive, modality-specific view. These results suggest that updating represents a modality-specific operation that depends on motor control, whereas shifting and inhibiting represent supramodal operations that act independently of motor control.

## 1. Introduction

An important question regarding human cognition concerns the extent to which higher cognitive functions are related to lower motor processes (e.g., Haggard, Rossetti, & Kawato, 2007). According to one view, cognitive functions concern supramodal representations and processes, which occur before modality-specific motor processes are engaged. Alternatively, cognitive processes operate directly on modality-specific motor-related representations, which implies a close relationship between cognitive functions and motor processes. The question of whether cognitive processes and representations are supramodal or modality-specific (and cognition is "embodied" or not, e.g., Pecher & Zwaan, 2005) has been investigated in several domains, including memory, language, and thinking. It has also been examined in the domain of cognitive control (Brass & von Cramon, 2007), which is the topic of the present article.

Cognitive control is an umbrella term covering several different abilities, and concerns the higher-level processes that regulate lower-level processes needed to remain goal-directed, especially in the face of distraction (e.g., Miller & Cohen, 2001). According to an influential proposal by Miyake et al. (2000), cognitive control comprises the three separable functions of updating, inhibiting, and shifting (see also Friedman et al., 2008). Updating is the ability to maintain and actively manipulate the contents of working memory, inhibiting is the ability to lower the interference of unwanted stimuli or responses, and shifting is the ability to switch back and forth between tasks or mental sets. In contrast to cognitive control, motor control entails the planning and selection of motor responses. It should be noted that the updating, inhibiting, and shifting components of cognitive control are separable but also correlated, as evident from a large-scale latent variable analysis by Miyake et al. (2000). Thus, experimental tasks and manipulations are unlikely to index the three cognitive control abilities in a pure fashion. Importantly, however, the three components nevertheless predominantly contributed to experimental tasks that were considered to mainly tap each component ability. Likewise, Sikora, Roelofs, Hermans, and Knoors (2016) observed that certain experimental manipulations (i.e., length, distractor, and sequence, to be discussed later) uniquely correlated with the updating, inhibiting, and shifting abilities, as measured by standard tests. Thus, although the updating, inhibiting, and shifting components are unlikely to contribute in a pure fashion to

* Corresponding author at: Radboud University, Donders Institute for Brain, Cognition and Behaviour, Centre for Cognition, Montessorilaan 3, 6525 HR, Nijmegen, the Netherlands.
*E-mail address:* M.Rietbergen@donders.ru.nl (M. Rietbergen).

https://doi.org/10.1016/j.actpsy.2018.09.008
Received 18 January 2018; Received in revised form 15 June 2018; Accepted 15 September 2018
0001-6918/ 

experimental tasks and manipulations, their contributions can be separated.

We first discuss previous studies that investigated the influence of response modality on shifting and inhibiting abilities separately. We do not know of any studies to date that investigated the influence of response modality on updating abilities. We then describe the limitations that arise from the paradigms that were used in those studies. Finally, we introduce our paradigm designed to avoid those limitations, and to better disentangle cognitive from motor control.

### 1.1. The influence of response modality on shifting

In a neuroimaging study on the modality-specific nature of cognitive control, Brass and von Cramon (2007) investigated whether switching reaction times (RTs) and brain activity were sensitive to manual and foot response modalities. Participants were instructed to attend to a series of symbolic cues and make either a parity (odd or even) or magnitude (smaller or larger) judgement concerning the numbers that would follow each cue. Depending on the direction of the judgement, they were instructed to press either a left or right button with the corresponding hand or foot. They found a switch effect, where RTs were shorter for cues that repeated task instructions, and longest for cues that switched between task instructions. A modality effect was also observed, in which RTs were shorter on manual than on foot trials. However, there was no interaction between switch and modality, meaning that the magnitude of the switch effect in the RTs did not differ between response modalities, suggesting that "cognitive-control-related processes… do not depend on response modality" (p. 112). In line with these behavioral results, functional magnetic resonance imaging (fMRI) during these tasks did not show an interaction between switch and modality within motor or control-related brain regions. An RT study by Philipp and Koch (2011) also assessed task switching with manual and foot responses, in addition to vocal responses. This study replicated the findings from Brass and von Cramon, such that the switch cost did not differ as a function of response modality. Taken together, these results are in line with a supramodal view.

The two aforementioned studies assessed the influence of response modality using a cued task-switching paradigm, which made use of an arbitrary stimulus-response (S-R) mapping. Brass and von Cramon (2007) describe this as a mapping where the behavioral response is not automatically evoked by the stimulus but rather guided by abstract rules. The abstract rules that guide behavior are less automatic, and this suggests that additional cognitive control is needed. Conversely, a non-arbitrary S-R mapping is one where the stimulus more automatically elicits a behavioral response. For instance, a visuospatial stimulus (e.g., a left or right pointing arrow, or a target in a particular spatial position) would more directly elicit a directional or spatial behavioral response (e.g., a left- or right-related button press). It is possible that the lack of an interaction between cognitive and motor processes in the studies of Brass and von Cramon and Philipp and Koch (2011) might reflect the use of arbitrary S-R mapping, because arbitrary mappings call upon additional control strategies (such as rule retrieval). Non-arbitrary S-R mappings have been used in studies using particular Stroop-like tasks, which have been associated with the inhibiting component of cognitive control (e.g., Miyake et al., 2000). We discuss these studies next.

### 1.2. The influence of response modality on inhibiting

Baldo, Shimamura, and Prinzmetal (1998) examined the influence of response modality using arrow-word, arrow-arrow, and word-word versions of a Stroop-like task. For instance, in the arrow-word version, congruent and incongruent combinations of the words *left* or *right* and left- or right-pointing arrows (e.g., the word *right* combined with an incongruent left-pointing arrow) were presented. Participants responded to the word while ignoring the arrow (the word task) or to the arrow while ignoring the word (the arrow task). Responses were made using either the right index finger (respond left) or right middle finger (respond right), or by saying "left" or "right". The Stroop-like effect is the difference in RT between incongruent and congruent trials. Despite vocal RTs being generally longer than manual RTs, they found that the magnitude of the Stroop-like effect was larger for the word task when manual responses were required compared to when vocal responses were required. Conversely, for the arrow task, the Stroop-like effect was larger for vocal than manual responses. In a different study, Turken and Swick (1999) compared behavior between age-matched healthy controls and a patient with a lesion to part of the motor area of the right hemispheric anterior cingulate cortex (ACC) involved in manual control. The ACC is commonly associated with cognitive control (e.g., Barch et al., 2001; Miller & Cohen, 2001). Their results replicated those of Baldo et al. in that the Stroop-like effect for the patient and controls was larger for manual than for vocal responses in the word task, and larger for vocal than for manual responses in the arrow task. The patient showed a disproportionally larger Stroop-like effect in manual but not in vocal responding. These findings reported by Baldo et al., and further supported by Turken and Swick, suggest that inhibiting abilities are not independent of response modality, in line with the modality-specific view.

However, in the study from Baldo et al. (1998), the effect of response modality was further investigated in word-word and arrow-arrow versions of the Stroop-like task, which showed no influence of response modality. Thus, when participants were presented with congruent and incongruent combinations of two words (i.e., *left* or *right*), or combinations of two arrows (i.e., left- or right-pointing arrows), different response modalities did not influence the magnitude of the Stroop-like effect. This suggests that the modality effect was dependent on the stimulus rather than on the response dimensions. When the target and distractor dimensions of the stimuli are the same (i.e., two words or two arrows), the magnitude of the Stroop-like effect for the arrow and word tasks is not influenced by response modality.

To conclude, the literature provides support in favor and against both the supramodal and modality-specific views. The studies described in detail above used paradigms that evaluated the influence of response modality on shifting and inhibiting abilities separately, making use of arbitrary or non-arbitrary S-R mappings with discrete binary responses, in particular, hand, foot, or vocal responses. The current study uses non-arbitrary S-R mappings with discrete and non-discrete responses, and with stimulus dimensions that were exactly matched between response modalities. Moreover, we assessed effects of response modality not only for shifting and inhibition, but also for updating, in a within-subjects design. The evidence in favor or against the supramodal and modality-specific views was quantified using Bayesian statistical analyses.

### 1.3. Assessing updating, inhibiting, and shifting in a single paradigm

To examine the influence of response modality on updating, inhibiting, and shifting, we adopted a flanker-like paradigm (Eriksen & Eriksen, 1974) that was modeled after a spoken noun-phrase picture-naming task used in a study by Sikora, Roelofs, Hermans, and Knoors (2016). In this study, picture-description RTs were evaluated between more-demanding and less-demanding trials, by measuring effects of length (i.e., the difference between trials with long phrases and short phrases, assessing updating), distractor (i.e., the difference between trials with incongruent and congruent distractors, assessing inhibiting), and sequence (i.e., the difference between switch and repeat trials, assessing shifting). For example, participants said "the fork" to a black-and-white picture of a fork (the short phrase condition) and "the green fork" to a fork in green color (the long phrase condition). They heard spoken distractor words that were either congruent ("fork") or incongruent ("spoon") with the picture name. The required phrase type changed every second trial, so that picture description RTs were obtained on repeat trials (a short trial preceded by a short trial, or a long