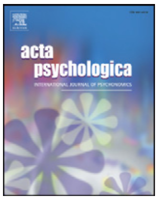
Acta Psychologica 155 (2015) 67–76

Contents lists available at ScienceDirect

Acta Psychologica

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



The role of crossmodal competition and dimensional overlap in crossmodal attention switching☆

Magali Kreutzfeldt [a],*, Denise N. Stephan [a], Walter Sturm [b], Klaus Willmes [b], Iring Koch [a]

[a] Institute of Psychology, RWTH Aachen University, Aachen, Germany
[b] Department of Neurology—Section Neuropsychology, Medical Faculty, RWTH Aachen University, Aachen, Germany

ARTICLE INFO

Article history:
Received 8 July 2014
Received in revised form 18 December 2014
Accepted 20 December 2014
Available online 8 January 2015

PsycINFO classification:
2300 Human Experimental Psychology
2340 Cognitive Processes
2346 Attention

Keywords:
Crossmodal selective attention
Modality switch costs
Congruency effect
Visual dominance
Dimensional overlap

ABSTRACT

Crossmodal selective attention was investigated in a cued task switching paradigm using bimodal visual and auditory stimulation. A cue indicated the imperative modality. Three levels of spatial S–R associations were established following perceptual (location), structural (numerical), and conceptual (verbal) set-level compatibility. In Experiment 1, participants switched attention between the auditory and visual modality either with a spatial-location or spatial-numerical stimulus set. In the spatial-location set, participants performed a localization judgment on left vs. right presented stimuli, whereas the spatial-numerical set required a magnitude judgment about a visually or auditorily presented number word. Single-modality blocks with unimodal stimuli were included as a control condition. In Experiment 2, the spatial-numerical stimulus set was replaced by a spatial-verbal stimulus set using direction words (e.g., "left"). RT data showed modality switch costs, which were asymmetric across modalities in the spatial-numerical and spatial-verbal stimulus set (i.e., larger for auditory than for visual stimuli), and congruency effects, which were asymmetric primarily in the spatial-location stimulus set (i.e., larger for auditory than for visual stimuli). This pattern of effects suggests task-dependent visual dominance.

1. Introduction

Mental flexibility as a crucial factor for adaptive behavior has been of great importance throughout human history. This flexibility enables us to switch quickly between different tasks. Usually, such task switches are associated with behavioral switch costs (Kiesel et al., 2010; Monsell, 2003; Vandierendonck, Liefooghe, & Verbruggen, 2010). Responses are generally slower and less accurate when participants have previously performed a different task than when they have executed the same task.

Two major accounts have been proposed as the source of switch costs in task switching: the reconfiguration view and the interference view (Kiesel et al., 2010; Vandierendonck et al., 2010, for reviews). According to the reconfiguration view, the source of switch costs is due to an updating or reconfiguration process of the cognitive system in response to a new task set. Because goals and task rules will be updated during this process, reconfiguration can be seen as an amodal process, which will take place regardless of the modality of the stimulus. In contrast, according to the (proactive) interference view, switch costs arise as the result of carry-over effects of activation of previously relevant task sets, or persisting inhibition of the prior irrelevant task sets ("task set inertia") (e.g., Allport & Wylie, 1999; Koch, Gade, Schuch, & Philipp, 2010, for reviews). In line with the interference view, modality-specific components of the task sets can contribute to switch costs in task switching.

However, so far task switching has rarely been investigated with an emphasis on modality-specific influences. The premise has rather been that task switching, and particularly the hypothesized process of task-set reconfiguration, is an intentional process independent of the modality at hand. For example, the existence of *amodal* attentional processes has recently been suggested by Dux and colleagues using neuroimaging techniques (Dux, Ivanoff, Asplund, & Marois, 2006; Tamber-Rosenau, Dux, Tombu, Asplund, & Marois, 2013). In light of this debate about the (a)modality of attentional processes, our investigation sets out to further examine the degree to which attentional processes are modality-specific vs. amodal.

1.1. Patterns of modality dominance in crossmodal attention

The issue of modality-specificity of flexible attentional control can be addressed in situations of modality competition, hence crossmodal situations with bimodal stimulation, where target modalities switch.

☆ This research was funded by the DFG (Deutsche Forschungsgemeinschaft; KO 2045/15-1). We would like to thank Linn Zulka and Verena Maag for data collection, and Robert W. Proctor and Durk Talsma for comments on an earlier version of this article.

* Corresponding author at: Magali Kreutzfeldt, Institute of Psychology, RWTH Aachen University, Jägerstrasse 17-19, 52066 Aachen, Germany. Tel.: +49 241 80 99372.
E-mail address: kreutzfeldt@psych.rwth-aachen.de (M. Kreutzfeldt).

http://dx.doi.org/10.1016/j.actpsy.2014.12.006
0001-6918/

Finding modality-specific dominance relations could indicate modality-specific components of attention.

In task switching research, studies usually involve visual stimuli, and only few studies raised the issue of modality-specificity of task sets. For example, Hunt and Kingstone (2004) asked their participants to perform two numerical tasks in a predictable "alternating-runs" task sequence, but the stimulus modality varied randomly (visual vs. auditory). Apart from the usual task switch costs, these authors also found a performance decrement whenever the target modality changed from one trial to the next (i.e., modality switch costs). However, as that study included only unimodal stimuli, we cannot draw conclusions with regard to modality dominance in crossmodal *selective* attention.

Likewise, Murray, De Santis, Thut, and Wylie (2009) used a cued task switching paradigm also with unimodal stimuli. They employed a "what/identity" and a "where/location" task to reduce crosstalk among different neural circuits subserving those tasks. In their Experiment 1, the task was cued but not the modality, while the modality was cued in their Experiment 2. The authors found task and modality switch costs. But again, the stimuli were unimodal, not requiring any *selective* crossmodal attention.

In contrast, Sandhu and Dyson (2013) used bimodal stimuli to examine crossmodal selective attention switching. They combined task switching (identity and position task) and modality switching (auditory and visual) in a cued task switching paradigm with bimodal and bivalent stimuli. They found task and modality switch costs. A combined switch of both task and modality evoked costs that were not significantly different from the costs of task switching or modality switching alone. However, Sandhu and Dyson (2013) focused mainly on separating the processes involved in task switching from the processes involved in modality switching. By comparison, we aimed at systematically varying modalities and stimulus material in modality switching to investigate crossmodal dominance in attentional control.

Using an experimental set-up similar to that used by Sandhu and Dyson (2013), Lukas, Philipp, and Koch (2010a,b) employed a spatial discrimination task for both the visual and auditory modality using bimodal and bivalent stimulus presentation and manual-spatial key-press responses (i.e., left vs. right). They found modality switch costs, which were of similar size across modalities. Importantly, they also found markedly asymmetric congruency effects, revealing a clear modality-specific difference in crossmodal attention.

In congruent trials of the studies by Lukas et al. (2010a,b), target and distractor modality ask for the same response (e.g., visual symbol and sound appear to the right, "right" is the shared stimulus feature), whereas in incongruent trials, target and distractor do not share common features and thus call for different responses (e.g., symbol to the right, sound to the left). The finding of a congruency effect shows that irrelevant stimulus features were processed to some degree. The congruency effect in the studies of Lukas et al. (2010a,b) indicated that the distractor presented in the other modality was also processed, causing crossmodal interference. Importantly, as stated above, this congruency effect was larger when the relevant stimulus was auditory rather than visual, suggesting relative "visual dominance", which refers to enhanced performance in response to visual compared to auditory stimuli in situations of crossmodal competition (e.g., Spence, Parise, & Chen, 2012, for review).

Based on this set of findings, the question arises as to whether modality dominance as observed by Lukas et al. (2010a,b) is an intrinsic aspect of visual processing in crossmodal attention tasks. Moreover, in order to establish worse performance with auditory targets as being due to visual modality dominance rather than to differences in mere task difficulty, it is important to include control conditions of single-modality trials. That is, single-task trials provide the opportunity to assess baseline performance in response to each modality separately, and single-task trials control for processing speed differences between modalities. Also, modality dominance might be determined by a modality-specific interaction of tasks and stimulus material (see also Sandhu & Dyson, 2012, 2013, for a discussion). In the present study, we examined this question by systematically varying stimulus material and compatibility of the associated stimulus–response (S–R) mapping.

1.2. Patterns of direct and indirect activation of spatial response codes

Lukas et al. (2010a,b) used a localization judgment task with "direct" spatially compatible S–R associations. According to Kornblum, Hasbroucq, and Osman (1990), S–R compatibility is a function of dimensional overlap between stimulus and response sets. Dimensional overlap refers to the "degree to which sets of items are perceptually, structurally, or conceptually similar" (Kornblum, 1994, p.130). Compatibility at the set level can therefore be divided into *perceptual*, *structural*, and *conceptual overlap* (Kornblum, 1994; Kornblum & Lee, 1995).

To study the degree to which the pattern of visual dominance found by Lukas et al. (2010a,b) generalizes to other spatial tasks and whether it is also found with less direct spatial dimensional overlap, set-level compatibility needs to be systematically varied. In the localization task used by Lukas et al. (2010a,b), stimuli and responses have *perceptual overlap* at the set level (i.e., common spatial dimension). In order to create conditions of "indirect" spatial dimensional overlap, we introduced a numerical judgment task, in which participants had to decide if a target number is smaller or larger than a reference number. It has been demonstrated that numerical stimuli carry spatial associations (Dehaene, Bossini, & Giraux, 1993), so that this stimulus set generates *structural overlap* between stimuli and manual-spatial key-press responses.

Specifically, Dehaene et al. (1993) discovered a now well established effect, called the SNARC effect (spatial numerical association of response codes). In their study, participants completed an even/odd-task on natural numbers. Results indicated that responses to smaller digits were faster with a left key press and responses to larger digits faster with a right key press. Therefore, numbers are thought to be "localized on a mental number line". Hence, numbers carry spatial meaning and with this mediating spatial associations. Notably, the SNARC effect also generalizes to number words (Nuerk, Iversen, & Willmes, 2004; Nuerk, Wood, & Willmes, 2005), which is important for the present study because number words can be presented both visually and auditorily. Although the number words as stimuli were centrally presented, the numbers themselves carry spatial associations. That is, even though there is no correspondence of numbers and response keys in terms of actual location, their structure in terms of spatial associations is similar to that of spatial-location stimuli. Proctor and Cho (2006) suggested an alternative account for the SNARC effect, interpreting it more categorically in terms of polarity correspondence in the mapping across stimulus and response sets. This alternative account invites even stronger predictions for crossmodal congruency effects with binary categorical number stimuli (i.e., smaller vs. larger numbers, or polarity correspondence (Proctor & Cho, 2006)).

In contrast to localization judgment tasks with direct, *perceptual overlap*, S–R associations in numerical judgment tasks are indirect, mediated via the mental number line (Dehaene et al., 1993), and thus have *structural overlap* (i.e., on the spatial dimension). We can thus compare results from direct perceptual spatial overlap to that obtained with indirect structural spatial overlap. Furthermore, by substituting symbols and sounds in the location task by centrally/binaurally displayed direction words (verbal codes), we also created a condition of *conceptual overlap* (i.e., verbal codes of "left" and "right" establish a spatial concept that overlaps with the representation of left or right key).

The use of verbal word stimuli relative to number stimuli (structural overlap) and location stimuli (perceptual overlap) could lead to different results with respect to visual dominance in spatial tasks. When the verbal codes pass through the semantic system, processing of auditory stimuli could be facilitated, so that the expected visual dominance could be weakened.