CROSS-MODAL PROCESSING AND COGNITIVE CONTROL

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Abstract

In managing our daily lives, we need to regulate information perceived from different modalities. It has been suggested that the inputs from these sensory channels are processed to some extent in independent modules (Fodor, 1983). The question whether executive control is module-specific or cross-modal in nature remains open.

In this study we focused on executive processes of switching and conflict resolution in both the tactile and visual modality. We explored the interaction of simultaneous and sequential implementation of executive control processes between and within modalities. Our results revealed asymmetric mixing costs and congruency effects between the tactile and visual modality. Switching cost was larger following incongruent trials, leading to the idea set switching and conflict monitoring are two different mechanisms of control, competing over resources and affecting each others' performance. Whether control is shared by various modalities or modality-specific is yet to be resolved.

In our daily life we often need to adapt to or react quickly to varied stimuli. When different tasks are required our adaptation includes switching and updating new tasks. In cognitive psychology the question of central versus modular processing is important and widely researched. Some processes have been shown to operate within a module while others have been shown to interact between modules (Fodor, 1983). Executive control processes are of main interest, related to healthy performance of humans. Among these processes are the ability to inhibit a response in order to prefer a more suitable one in a certain situation, and switching between tasks as a flexible ability of human performance. It is important to understand whether various executive processes are modality specific or central in nature.

The current work employed a visual-tactile task switching task to examine cross-modal effects (i.e., switching cost and conflict resolution effect).

Within cognitive control literature two independent mechanisms have been suggested, *trial-to-trial adaptive control* and *strategic general block-based control* (Hommel, Proctor, & Vu, 2004; Aisneberg & Henik, 2010). Trial-to-trial adaptive control is a differential application, assumed to be updated by the need of control following every step (Botvinick, Carter, Braver, Barch, & Cohen, 2001). Strategic general block-based control is assumed to be updated by the strategy taken by the participant, according to expectations or knowledge regarding the conflict to address (Logan & Zbrodoff, 1979). Testing the flexible human behaviour of set switching and control adaptation is commonly done by using a cognitive paradigm called ‘task switching’ (see Monsell, 2003 for review). In a typical task-switching block participants are asked to perform two different tasks (e.g. A and B). In the sequence of the trials, some are repeat trials; both previous and current trial are of the same task type (e.g. AA or BB), whereas some are switch trials; the current task is different from the previous one (e.g. AB or BA). Performance in switch trials is usually slower and less accurate than in repeat trials. This impairment is called switching cost (SC) (e.g., Allport, Styles & Hsieh, 1994; Rogers & Monsell, 1995). The difference between performing repeat trials in a two task block and performing the same trials in a single task block is called Mixing Cost (MC). The MC represents the cognitive difference in complexity of preparing to the next task. Demonstrating cognitive control effects with task switching paradigm can be understood as follow: The strategic general block-based control is reflected in mixing cost and congruency effects (Logan & Zbrodoff, 1979); the trial-to-trial adaptive control is reflected in the reduction of the switching cost (task reconfiguration) and sequential congruency effects (Ridderinkhof, 2002).

One way to inform participants when to switch between tasks or repeat the previous task is by task cuing (Meiran, 1996; Monsell, 2003). Allowing a randomised sequence of trials, a cue is presented prior to the appearance of the target, indicating the task to execute in the upcoming trial. Previous studies have showed that longer cue-target interval (CTI) was more effective in preparing for the next task demands (e.g., Koch, 2003; Meiran, 1996, 2000b), including response modalities (vocal, manual, and pedal responses; Philipp & Koch, 2005).

Meiran (2000) suggested that this cueing effect is based on selection process of the relevant stimulus dimension. This process is mainly relevant in switch trials, since in repeat trials the relevant dimension is already preferred. In trials with short preparation (CTI) interval, this process of biasing is not accomplished until stimulus appears and thus, longer duration is exhibited in performance. However, this idea of preferring a task-relevant stimulus dimension has only been explicitly tested within the visual modality (Lukas, Phillip and Koch, 2010). Cue-target preparation for attending stimuli in different modalities has been hardly examined yet. Previous studies of cross-modal attention dealt with preparation effects and used a single-task design. For example, Spence and Driver (1997) examined the ability to attend to changing stimulus modalities (detecting visual or auditory stimuli), and found that stimulus detection was faster when two successive stimuli appeared in the same modality than when they appeared in different modalities (“stimulus-modality switch costs”). They also found that participants were able to successfully prepare for the upcoming stimulus after a valid cue of the modality of the next stimulus, compared to an invalid cue. Murray, De Santis, Thut, and Wylie (2009) found that valid cues improved switching costs only for the visual stimulus modality. In a different study, Quinlan and Hill (1999) manipulated CTI and found that in the long CTI participants effectively prepared for the upcoming stimulus modality (seen in smaller switching cost), compared with short CTI. They concluded that the underlying attentional processes are modality-specific. It seems that we have the ability to prepare for changing stimuli in different modalities. But can we benefit from ignoring distraction in one modality, and become better ignoring distraction in another modality?

In order to test cross-modal attention effects, bivalent stimuli are needed in task switching paradigm, that consist of two different target features, each from different modality, and each can be either task relevant or task irrelevant in every trial. Meiran (2000, 2008) wrote that bivalent stimuli require focusing attention on task-relevant feature to overcome the conflict resulting from competing S–R bindings of the task-irrelevant features. It is important to note here, that none of the studies mentioned above used bivalent stimuli.

Recently, Lukas et al., (2010) used bivalent stimuli to test attention switch between two modalities (visual and auditory). They used overlapping S–R mappings to examine if the assumed attentional processes are strong enough to overcome interference from a stimulus in another modality that shares the same response set. They found a clear preparation effect for attention shift between modalities, as RT after a long CTI decreased significantly compared to after short CTI. Moreover, CTI manipulation affected the switching costs. The authors noted that preparation is independent from automatic priming effects resulting from a corresponding cue-modality/stimulus-modality mapping. Yet, gaining benefit from conflict solving in one modality to conflict solving in another modality was yet to be tested.

It is interesting to broaden cross-modal findings testing other control applications and other modalities; Specifically, testing the ability to gain benefit from solving a conflict in one trial to another (see sequential dependencies in Gratton et al., 1992; Botvinick et. al, 2001) when these trials stimuli are from different modalities. Our study examined cross-modal effects of switching cost and conflict resolution using tactile and visual modalities.

Miles, Brown and Poliakoff (2011) showed that both tactile and visual targets lead to a reliable modality shift effect (MSE): responding to stimulus leads to faster RT for subsequent stimuli in the same modality. They revealed that target-induced MSE diminishes with increasing inter-trial intervals. Tactile targets showed greater MSE than did visual targets. The authors suggested it's easier to shift attention from touch to vision than vice versa, because visual targets attract attention more strongly towards their modality, consistent with a visual dominance hypothesis (e.g., Posner et al., 1976). In contrast, Spence et al. (2001) found asymmetries between modalities (visual, auditory, and tactile), in which shifting attention away from tactile stimuli was associated with greater costs than shifting away from vision and audition. Miles et al., (2011) referring to Spence et al. (2001), concluded that in contrast to spatial attention, where cue affects subsequent stimuli at location regardless of its' modality, a modality cue doesn't carry over to stimuli at different spatial locations.

The current study

Here we ask whether strategic general block-based and trial-to-trial adaptive control processes are cross-modal or uni-modal in nature**.** Regarding the strategic general block-based control process, we hypothesized a modality specific mechanism; hence, mixing cost presented for each modality may differ in magnitude, suggesting vulnerability to the disturbance of the other modality. We expected the visual modality to suffer larger mixing cost. We also hypothesized that significant congruency effect will be found, as an indicator for strategic general block-based control, but different effects will be seen in each modality, according to its' RT. Regarding the trial-to-trial adaptive control mechanism, we hypothesized a cross-modal process. This predicts that dealing with a conflict when attending to one modality would enhance solving a conflict when attending to other modality in the following trial. Yet, within the cross-modal trial-to-trial adaptive control mechanism we hypothesized some asymmetry between modalities. In sequential congruency effects we expected tactile performance to gain benefit from solving a conflict in previous visual conflict trial, while a current visual trial may gain less benefit or none.

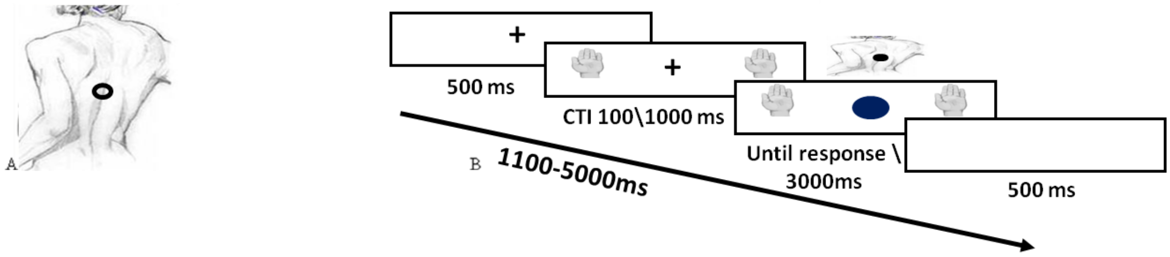
Before testing our hypotheses a pilot study was conducted, using the Garner task for examining the ability to differentiate stimuli while ignoring distractors from other modality (Garner, 1974). 16 undergraduate students participated in this experiment, half performed 2 blocks of Garner task with tactile targets (1. tactile targets and one visual distractor. 2. Tactile targets and varying visual distractors), and half with visual targets and tactile distractors. No significant Garner effect was observed, suggesting both tactile and visual modality’s are separable when presented together.

Method

Participants. 16 new undergraduate students (aged 21 to 27 years old, 8 females) took part in the experiment for partial fulfillment of course requirements.

Apparatus. Data collection and stimulus presentation were controlled by a Compaq computer with an Intel Pentium III central processor. A keyboard was placed on a table between the participant and the monitor. The experimental system was controlled by E-prime 2.0 software (Psychology Software Tools, Pittsburgh, PA). Visual stimuli were presented on a Compaq S510 monitor. Tactile stimuli were produced by a C2 tactor (i.e., vibrating tactile actuator) powered by the controller Eval 2.0 (Engineering Acoustics Inc.). The tactor, stitched to an elastic-fiber strap, worn around the torso, was centered on his/her back (see Figure 1a). Vibrating sounds were eliminated by active white noise headphones (ATH-ANC7, Audio-Technica).

Figure 1. A. Layout of tactors on the back, circles indicate the position of the tactors. B. Example of experimental trial



Stimuli. Visual stimulus was a red/blue patch displayed on the center of the screen. The vibrotactile stimulus was either (a) continuous—a 250 Hz vibration, felt as a single "bzzzz" or (b) pulsed— a 250 Hz vibration with a modulation of 10 beats per second, felt as "bzz…bzz…bzz". The keys representations were balanced between participants (e.g. For 25% "D" represented red/continuous and "L" blue/pulsed). Consequently, there were two different incongruent stimuli and two different congruent stimuli. Tactile cue displayed two "hand" icons and visual cue displayed two "eye" icons on the left and right central horizontal meridian of the screen.

Procedure. Participants were seated isolated in front of a computer. First, the experimenter verified the tactor was sensed and comfortably placed on the participants' back. They were than familiarized with the sensation of tactile stimuli. Instruction was given to respond to the visual (visual task) or the tactile (tactile task) stimulus according to the indicating cue (see Figure 1b). Seven experimental blocks consisted of four randomly mixed trials blocks, of both visual and tactile tasks (mixed), followed by two visual task only and tactile task only blocks (pure). Seventh block was a mixed block. Practice block included 16 trials of both visual and tactile tasks. Mixed-blocks and pure-blocks included 104 and 52 trials, respectively.

Design.Task (visual, tactile), block (mixed, pure), congruency (congruent,incongruent), previous (congruent, incongruent) CTI (100, 1000ms) and switch (switch, repeat) manipulated within participants.

Results

Mean RTs for correct responses as well as two standard deviations above and below mean RT were calculated for each participant in each condition. Extreme results were excluded from the analysis. Error rate was very low (4.5%) and therefore errors were not analyzed.

The results of the two pure blocks were united under the condition 'pure'. Significant main effects were found: congruency effect of 33ms (726ms and 693ms for incongruent and congruent, respectively) [$F(1, 16) = 7.6$, $\eta^2 = 0.32$, $MSE = 30{,}245$, $p < .014$], suggesting task multi-modal stimulus had succeeded in generating two competing demands; switching effect of 180ms [$F(1, 16) = 69.95$, $MSE = 29{,}347$, $p < .000$]; CTI effect [$F(1, 16) = 29.82$, $\eta^2 = 0.65$, $MSE = 56{,}809$, $p < .000$] suggested that preparation took place following the cue's display (755ms and 664ms for 100ms and1000 ms, respectively) and longer preparation time led to faster RT; effect of block [$F(1, 16) = 33.17$, $\eta^2 = 0.67$, $MSE = 49{,}532$, $p < .000$]. Planned comparison revealed that mean RT for the five mixed blocks was slower than for pure block (745ms and 533ms, respectively) [$F(1, 16) = 31.34$, $MSE = 62{,}645$, $p < .000$]. The learning curve was observed among the first four mixed blocks and further improvement in the last mixed block that was given after the pure blocks. Significant two way interactions were found; block and CTI [$F(1, 16) = 3.14$, $\eta^2 = 0.16$, $MSE = 16{,}451$, $p < .012$], revealing larger preparation effect in the mixed compared to pure blocks; CTI and switch [$F(1, 16) = 25.04$, $MSE = 8{,}203$, $p < .000$], suggesting, as expected, that the longer the time to prepare, the smaller the switching cost is; switching and previous (congruency of previous trial), [$F(1, 16) = 13.38$, $MSE = 3{,}545$, $p < .002$] (see figure 2b).

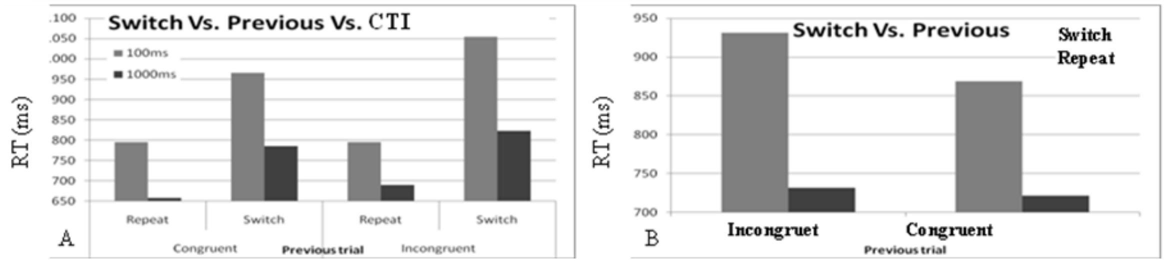


Figure 2: Mean RT for task switching effects: A. Switch Vs. previous Vs. CTI interaction B. Switch Vs. previous interaction

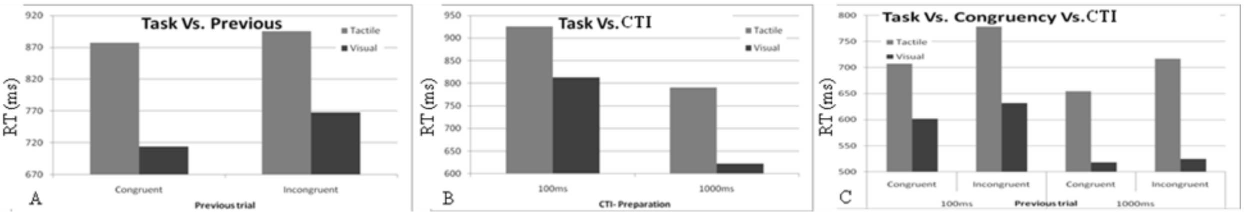
Switching cost was larger following incongruent trial than following congruent trials (200ms and 147ms, respectively). This result may provide first evidence that control required for task preparation is affected by control demanded by the conflict resolution of the previous trial, regardless of task's modality. A significant three way interaction between CTI, switch and previous was also found [$F(1, 16) = 8.09$, $MSE = 8{,}766$, $p < .011$], revealing that switching cost is greatest on short preparation following an incongruent trial (see figure 2a).

For evaluation of modality effects, avoiding learning effects, the results of the third and fourth mixed blocks were united under the condition 'mixed' and used for further analysis. Significant main effects for modality was found [$F(1, 16) = 85.77$, $\eta^2 = 0.84$, $MSE = 60{,}993$, $p < .000$]. Mean RT for a visual task was faster than for a tactile task (630ms and 790ms, respectively), as seen in previous tasks. Significant two way interactions were found: block and task [$F(1, 16) = 9.8$, $MSE = 4{,}701$, $p < .006$]; comparing repeat trials from pure to those from mixed blocks showed higher MC (mixing cost) for visual tasks (257ms) relative the tactile tasks (205ms); task and previous [$F(1, 16) = 8.05$, $MSE = 2{,}647$, $p < .011$], suggesting visual task is more affected by the conflict in the previous trial (see figure 3a). RT of visual tasks were 54ms faster when preceded by a congruent trial (768ms following incongruent, 714ms following congruent), whereas the tactile task was not affected by the congruency of the previous trial (895ms and 877ms, respectively); Task and CTI [$F(1, 16) = 7.49$, $MSE = 7{,}067$, $p < .014$] (see figure 3b), suggesting that visual task benefits more from prolonged preparation phase (CTI effect for visual tasks and tactile tasks, 191ms and 135ms, respectively). Simple effects revealed that congruency effect was significant in the tactile task [$F(1, 16) = 12.80$, $MSE = 5{,}135$, $p < .002$] and nearly reached significance in the visual task [$F(1, 16) = 3.59$, $MSE = 4{,}234$, $p < .075$]. Testing three-way interaction of Task, congruency and CTI revealed that this congruency effect only appeared in tactile modality when long preparation was available [$F(1, 16) = 4.92$, $p < .041$] (see figure 3c). This finding is in-line with the higher MC measured for the visual task, suggesting visual modality was more affected than the tactile one. No significant interaction was found between task and switching [$F(1, 16) < 1$], suggesting that the SC was similar in both modalities. The two way interaction between congruency and previous did not reach significance [$F(1,16)<1$], although for the visual task a Gratton effect trend was visible.

Discussion

Our results showed robust switching cost, mixing cost and preparation effects, as expected in task switching paradigm. Interaction between preparation (CTI) and switch revealed that longer preparation time decreased switching cost compared to short preparation time. An interesting finding was that the switching cost was larger following incongruent trials than following congruent trials. Moreover, this greater switching cost following an incongruent trial was greatest on short preparation (i.e. CTI of 100ms). According to the common explanation of Gratton effect (Botvinick et. Al., 2001), dealing with a conflict in trial N-1 (incongruent trial) should assist solving a conflict in the following trial N. Switching between trials is a conflicted situation, but,

Figure 3: Mean RT for effects of modalities:A. task Vs Previous interaction B. task Vs. CTI interaction C. task Vs. Congruency Vs. CTI interaction



as our results reveal, does not benefit from previous conflict solving of a different type. This result may provide first evidence that control needed for task preparation (switching) is affected by control demanded by the conflict resolution of the previous trial (incongruent trial on N-1). This calls for examination whether this is a result of control overload for same processes overlapping or a result of different mechanisms (for switching between tasks and conflict monitoring) competing over resources. If the known sequential effect would have been present here it would have supported the idea of two different mechanisms, as conflict monitoring does gain benefit from congruency conflict solving in trial N-1 to conflict solving in trial N, and task switching does not. Since this was not the case here, this question is yet to be determined.

Results of cross-modal processing revealed that the visual task was more affected by the conflict in the previous trial than the tactile task. Moreover, in the visual task a larger preparation effect was present, showing greater benefit in long preparation time. Higher mixing cost measured for the visual task, and significant congruency effect in tactile modality, but only a trend of that type in the visual modality. These findings suggest that the complexity of the tasks affected the visual modality more than the tactile one; Recruiting control to perform a much more complex task (as task switching with bivalent stimuli) increased RT significantly in the visual modality, created a controlled performance and hence, eliminated the congruency effect. Yet, it is possible that the larger mixing cost seen in the visual modality was a result of faster RT to begin with and not asymmetric costs between modalities. Our results did not reveal differences in sequential effects between visual and tactile modalities. It is possible that stimuli characteristics interfered with sequential benefit gaining from one conflict solving to another. Namely, maybe the fact that modality distractor to ignore in one trial was the modality target to address in the next one, made it too difficult to maintain this process while switching between tasks. On the other hand, this might support the idea of two different mechanisms of control (set switching and conflict monitoring), as the need to switch between tasks comes between two trials of conflict and interferes in conflict monitoring continuation.

To summarize, our results revealed asymmetric mixing costs and congruency effects between the tactile and visual modality. Our findings support the findings of Spence et al. (2001), suggesting that shifting attention away from tactile modality was associated with greater costs. Switching cost was larger following incongruent trials, leading to the idea of two different mechanisms of control, set switching and conflict monitoring, competing over resources and affecting each others' performance. Future research should be performed using congruency conflicts within modalities and not between, to better evaluate reciprocal effects of conflict solving from one modality to another.

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