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Abstract

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A conflict monitoring account of

the control mechanisms involved in dual-tasking

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ABSTRACT

The present study investigates the cognitive mechanism underlying the control of interference during dual-task coordination. Partially inspired by the Conflict Monitoring Hypothesis (Botvinick et al., 2001), we test the assumption that dual-task interference is resolved by a top-down adaptation mechanism that is responsible for behavioral adjustments in the prioritization of the coordinated tasks. In a series of two experiments, we measured conflict adaptation to the so-called Gratton effect—the decrease in dual-task interference following incompatible trials. In Experiment 1 the primary task was a low demand choice discrimination task, while in Experiment 2 the primary task was an updating task that imposes a continuous load on working memory. The secondary task was a tone discrimination task. Both experiments consistently showed that the response conflict of previous trial triggers top-down behavioral adjustments that reduce interference. We conclude that dual-task interference shows strong similarities to Stroop-like types of cognitive interference, namely in the way that suboptimal performance is dealt with by the cognitive system.

Executive functions can be generally described as a set of abilities required to intentionally guide behavior towards a goal, especially in novel or non-routine situations (Banich, 2009). Various tasks are believed to rely on executive functions. These include prioritizing and sequencing behavior, inhibiting familiar or automatic behaviors, creating and maintaining an idea of what task or information is most relevant for current purposes, providing resistance to information that is distracting or irrelevant to the current goal, switching between tasks, utilizing relevant information in support of decision making, categorizing elements, and managing novel information or situations. Executive control processes like inhibition, task-switching, updating, and dual-task coordination have been extensively investigated during the past decades (e.g. Miyake, Friedman, Emerson, Witzki, Howerter, & Wager, 2000; Chan, Shum, Toulopoulou & Chen, 2008). One of the least well understood of these functions is dual-task coordination, in which participants are required to perform two tasks simultaneously. The literature on multitasking suggests that people generally cannot make decisions or select responses in two different tasks at the same time (see Pashler, 1994). Performing two concurrent tasks usually affects performance on both tasks (i.e. dual-task cost or dual-task interference). In order to optimize dual-task performance, an executive control mechanism is supposed to efficiently divide cognitive resources between the different tasks (McCann & Johnston, 1992). Bottleneck theories propose that some processing needed to perform each task requires access to a processor that can only act on one input at a time (Pashler, 1994). If both tasks require the processor simultaneously, then only one can get access to it. While this processor is busy with one task, processing for the other task must be suspended until the processor is free. An alternative to this explanation is the central capacity sharing model (Tombu & Jolicœur, 2003), which suggest that tasks must share the available processing capacity because resources are limited. Thus there is an increase in the duration of processing during the period in which capacity is shared. However, the nature of the executive control mechanism underlying dual-task coordination remains unclear to this day.

The current study investigates dual-task coordination within the framework of the Conflict Monitoring Hypothesis (Botvinick, Braver, Barch, Carter, & Cohen, 2001). Conflict monitoring is regarded as a cognitive control function that monitors the occurrence of conflict or interference in information processing. In their seminal work, Botvinick and colleagues proposed that conflict monitoring processes serve to adjust the level of control. According to this account, the occurrence of conflict triggers top-down behavioral adaptations by which

conflict is reduced or resolved. The conflict monitoring hypothesis is based on a set of behavioral observations that appear to reflect on-line reactive adjustments in control. An example of this conflict adaptation mechanism is provided by Gratton, Coles, and Donchin (1992). Their study provides evidence for a sequential adaptation effect in the Eriksen flanker task (Eriksen & Eriksen, 1974). The flanker task requires a left or right response depending on the identity of a centrally presented target symbol. This target is surrounded by distracting flanker symbols that are either compatible (e.g. < < **<** < <) or incompatible (e.g. < < **>** < <) with the required response. Incompatible flanker trials are usually processed slower than compatible ones. Gratton et al. (1992) investigated the effects of trial-type transitions (compatible – compatible [C-C], compatible – incompatible [C-I], incompatible –compatible [I-C], and incompatible – incompatible [I-I]) and found that the conflict effect (reaction times for incompatible minus compatible trials) was reduced after incompatible trials. The occurrence of an incompatible trial thus appears to enhance target processing and/or suppress flanker processing on the following trial.

The observed effect is explained as follows: after an incompatible trial, high top-down control is exerted to attend the relevant task dimension (e.g. naming the ink color in the Stroop task or focusing on the central arrow in the flanker task) and produce the correct response. Then, when another incompatible trial is presented under conditions of high control, the subsequent conflict effect is smaller. We can label this as a situation of high control and low conflict. By contrast, after a compatible trial, there is no need for top-down regulation and few control resources are deployed; conflict is higher when an incompatible trial is presented, as evidenced by a stronger conflict effect. This situation can be labeled low control and high conflict. The modulation of conflict effects as a function of control level is believed to reflect the workings of the control mechanism described in the Conflict Monitoring Theory (Botvinick et al., 1999). As argued by Botvinick and colleagues (1999, 2001), these findings appear to provide an example of the reactive adjustments in control posited by the conflict monitoring hypothesis: incompatible trials involve response conflict, and it is this, according to the theory, that causes them to be associated with a subsequent intensification of top-down control.

It has been demonstrated that in addition to the flanker task, this control mechanism underlies performance in many of the popular interference and inhibition tasks like the Simon task (Sturmer, Leuthold, Soetens, Schroeter & Sommer, 2002; Wuhr & Ansorge, 2005), Stroop task (Barch, Braver, Akbudak, Conturo & Snyder, 2001; Egner & Hirsch, 2005a, 2005b; Kerns, Cohen, MacDonald, Cho, Stenger & Carter, 2004), and Go/No-go task

(Menon, Adleman, White, Glover & Reiss, 2001; Nieuwenhuis, Yeung, Van den Wildenberg, & Ridderinkhof, 2003). A more recent study (Szmalec, Verbruggen, Vandierendonck & Kemps, 2011) found evidence for Gratton-like adaptation effects in a 2-back updating task involving lure trials, i.e. trials that elicit proactive interference. For example, the trial B-*F*-K-*B* requires a negative 2-back response, but the negative response is typically slowed by the erroneous tendency to respond positively following activation of the letter B in the non-target 3-back position. Szmalec et al. (2011) observed that lure interference was reduced when following another lure trial compared to when following a neutral mismatch trial (e.g. M-*F*-K-*B*), and they concluded that the interference control mechanism represented by the Conflict Monitoring Hypothesis is also involved in the executive control function of memory updating.

At the neurological level, conflict monitoring (CM) is believed to be a function of the anterior cingulate cortex (ACC) (Botvinick, Nystrom, Fissell, Carter & Cohen, 1999; Botvinick, Cohen & Carter, 2004), which is located on the medial surface of the frontal lobes. Top-down adaptations following the detection of conflict by the ACC is understood as a selective activation of relevant task demands stored in the dorsolateral prefrontal cortex (DLPFC) in order to resolve the interference or conflict and optimize goal-directed behavior (see Davis, Hutchison, Lozano, Tasker & Dostrovsky, 2000). The DLPFC is a part of the frontal lobes that is believed to be a regulative, adaptive device that resolves conflicts by activating task-appropriate behavior based on the task-demands that are being represented (Miller & Cohen, 2001; Alvares & Emory, 2006). This interaction between an evaluative function (i.e. conflict monitoring) at the level of the ACC and a regulative function (i.e. conflict adaptation and administration of cognitive resources) at the level of the DLPFC offers a cognitive control mechanism that has been recognized as very effective and influential in the conflict literature (see Carter & van Veen, 2007 for a review).

The goal of the present study is to test the hypothesis that the conflict monitoring/control mechanism is also involved in dual-task coordination. Our hypothesis is based on the following two considerations: Firstly, dual-tasking has been put forward as an executive control function (e.g. Baddeley, 1996), and it can be argued that resolving the interference occurring in both conflict tasks (such as the Stroop task or the flanker compatibility effect) and dual-tasks demands higher executive control engagement than non-conflict tasks. In the case of conventional interference tasks, conflict is understood as a competition between an automatic and a controlled process, like word reading and color naming in the Stroop task necessitating executive control processes to overrule the incorrect automatic activation. In dual-task coordination, however, when the processing of two stimuli

that belong to two different tasks is performed, a competition arises between the processing of Task A and Task B, causing so-called cross-task interference (Pashler, 1994; Monsell, 2003). Here the response selection processes require control processes to proceed with bottleneck overlap, and processes only one task at a time (Lien, Ruthruff & Johnson, 2006) or shares the available processing capacity (Tombu & Jolicœur, 2003). Secondly, it has also been demonstrated that both the DLPFC and ACC are activated during dual-task performance (Sala, Baddeley, Papagno & Spinnler, 1995; Szameitat, Schubert, Muller & von Cramon, 2002; Botvinick et al., 2001). Given the role of the ACC in conflict monitoring, the latter finding is in line with the hypothesis that the ACC-DLPFC control mechanism is engaged in dual-task performance. The experiments presented below are aimed to investigate whether the executive control mechanism involved in traditional conflict tasks also underlies dual-task performance. In order to investigate whether this control mechanism is also involved in dual-tasking and assess the functioning of the cognitive control mechanism in behavioral measures, we measured Gratton-like top-down adaptation effects (Gratton et al., 1992). Therefore, it was investigated whether dual-task performance also yields top-down conflict adaptation behavior. More precisely, it was assumed that the conflict effects (i.e. dual-task interference effect) would be reduced if followed by a conflict trial (dual-task) relative to being followed by another non-conflict trial (single-task). To do so, we asked participants to name the color of letter strings as a main/primary task and presented them simultaneously with tone discrimination in half of the trials as a secondary/dual task.

Experiment 1

Method

Subjects

Twenty undergraduate students (10 female and 10 male) from the University of Social Sciences & Humanities participated in the experiment. All participants received credit points for their participation.

Apparatus and stimuli presentation settings

Participants were tested on a Pentium computer running Super-Lab 4.5 software and sat in front of a computer screen at a viewing distance of approximately 60 cm. All stimuli were presented centrally on a 15-inch color monitor, and the size of the letter strings was 72

points. The tones lasted for 250ms and were presented via earphones at two different frequencies: 300 Hz and 1100 Hz. The responses were made by pressing the "z", "c", ",", or "/" keys on the keyboard; these keys were labeled with the numbers "1", "2", "3" and "4" for the experimental procedure. All other keys were discarded during the experiment.

Procedure

All participants performed the dual task, where the primary task was to name the color (red or green) of a letter string (for all trials it was "XXXXX"). On dual-task trials a tone was presented along with letters and participant had to discriminate whether the tone was high or low.

Instructions and sample presentations were given on a computer screen at the beginning of the experiment and the need to respond as fast as possible while trying to avoid an error was stressed. Participants were asked to maintain fixation on the centre of the screen before each target was presented. Each subject was presented with 16 practice trials followed with 192 experimental trials, which were divided into 3 blocks (64 trials in each block) separated by short, 30 second breaks for participants to rest. The participants were instructed to press the key "1" or "2" in order to indicate the color of letter string and "3" or "4" to respond to the tones. The opposite mapping was used for the other participants. Indications for possible answers were presented at the bottom of the screen after each trial. There were no suggestions regarding task priority, so participants could decide which stimulus to respond to first.

The sequence of events on each trial was as follows: a fixation point was displayed for 500ms, after which a letter string appeared for 250ms and was simultaneously accompanied by a tone in the case of dual task trials. Half of the trials were single-task (only letters) and the other half were dual-task (letters and tone), presented in random order within blocks. Participants were given 3000ms to respond, after which the next trial was began. A lack of response within this time was recorded as "no-response". There was a 2000ms blank screen gap between trial presentation. Responses were provided with feedback: small crosses appeared on the screen to assure participants that their reaction was recorded. Both correct and error responses were recorded.

Results

Analyses were conducted on reaction times (mean raw RTs in milliseconds for correct responses to the primary task – i.e. color naming, responded to first) in order to compare reactions to the same task under different load conditions, and error rates (the proportion of incorrect responses in all trials; for dual task, responses from both the primary and secondary task were included to score accuracy). The data were then analyzed with 2x2 repeated measure ANOVA, with type of current trial (S - single vs. D - dual) and type of the previous trial (s - single vs. d - dual) as independent variables.

Analysis of RTs revealed one significant main effect, showing that responses for the primary task in dual-task trials were slower than for single trials (M_D = 731 ms, SD = 166 vs. M_S = 666 ms, SD = 147): $F(1,19)$ = 29.49, $p < .001$, η^2 = .61. As can be seen on Figure 1 this difference was present for both types of previous trial conditions. RTs for dual trials were longer compared to single trials if the previous trial was single (M_{sD} = 730 ms, SD = 175 vs. M_{sS} = 601 ms, SD = 118), $F(1,19)$ = 28, $p < .001$, η^2 = .60 , as well is if the previous trial was dual (M_{dD} = 774 ms, SD = 177 vs. M_{dS} = 687 ms, SD = 154), $F(1,19)$ = 24.9, $p < .001$, η^2 = .57. The effects were qualified by the nature of the relation between the current and previous trials, and thus the interaction between the type of trial and the type of previous trial was significant: $F(1,19)$ = 8.36, $p < .01$, η^2 = .31. In both cases primary tasks performed after dual-task trials were slower. However, reaction time incenses were larger for single (from M_{sS} = 601 ms, SD = 118 to M_{dS} = 687 ms, SD = 154) task than for dual task (from M_{sD} = 730 ms, SD = 175 to M_{dD} = 774 ms, SD = 177) trials: $F(1,19)$ = 37.07, $p < .001$, η^2 = .66 and $F(1,19)$ = 11.8, $p < .01$, η^2 = .38, respectively.

Figure 1 here

The error data (see figure 2) showed that in general trials performed after dual-task trials were more accurate than trials performed after single-task trials (M_d = .12, SD = .12 vs. M_s = .14, SD = .14), observable as the significant main effect of type of previous trial: $F(1,19)$ = 7.45, $p < .05$, η^2 = .28. Further analysis revealed that this is mainly due to the better accuracy of dual trials performed after other dual trials relative to those performed after single trials (M_{dD} = .11, SD = .13 vs. M_{sD} = .32, SD = .15: $F(1,19)$ = 8.45, $p < .05$, η^2 = .31). There were no significant differences in accuracy for single-task trials as there was no significant interaction.

Additionally, we looked at the task prioritization for dual-task trials and found that in 87.6% (SD=19.3%) of all dual trials color naming task was performed as a primary task and tone discrimination as the secondary. To see how this strategy influenced task performance, we compared the refractory periods for primary and secondary tasks (Lien, Ruthruff & Johnston, 2006). Using 2x2 repeated measure ANOVA, we compared the proportions of time needed to respond firstly to the primary (color naming) and then secondary (tone discrimination) task within dual-trials (type of trial: primary vs. secondary), performed either after single or dual trials (type of previous trial: single vs. dual) – see figure 3. The analysis revealed that in general secondary tasks were performed faster than primary tasks (M_{Sec} = 453 ms, SD = 210 vs. M_{Prim} = 766 ms, SD = 176; $F(1,19)$ = 29.97, p < .001, η^2 = .61), with a significant interaction between task type and previous trial type: $F(1,19)$ = 29.97, p < .001, η^2 = .61. This was due to faster responses to the primary task when performed after a single trial ($M_{Prim-single}$ = 730 ms, SD = 175) than after another dual trial ($M_{Prim-dual}$ = 774 ms, SD = 177): $F(1,19)$ = 11.8, p < .01, η^2 = .38. The cognitive slack for the secondary task was reduced when performed after a dual trial ($M_{Sec-dual}$ = 400 ms, SD = 179) compared to those performed after single trials ($M_{Sec-single}$ = 503 ms, SD = 241): $F(1,19)$ = 10, p < .01, η^2 = .35. Importantly, there was a trend level difference –showing that the overall time needed to respond to a dual task trial after a single task trial was slightly longer than after another dual trial: $F(1,19)$ = 3.41, p = .08 (M_{single} = 1233 ms, SD = 308 vs M_{dual} = 1174 ms, SD = 271).

Discussion

The present experiment tested whether conflict monitoring mechanisms can account for control of interference during dual-tasking. We investigated whether dual-task performance

also yields Gratton-like conflict adaptation effects (Gratton et al., 1992). The results confirmed our prediction: performance in both single and dual task conditions was modulated by the nature of the previous trial. The cost of adapting to a high control demanding task (i.e. dual task) performed after a low control demanding (i.e. single task) was smaller than after another demanding task. This can also be concluded when comparing dual task performance. The refractory period needed to process the secondary task was reduced if the dual task was performed after another dual trial. The error data also supports the conflict adaptation hypothesis. As can be seen on the graph (see figure 2), increased control after a conflict trial resulted in higher accuracy. This stands in line with previous observations that accuracy functions for compatible and incompatible trials is sorted on the basis of the compatibility level of the previous trial (Gratton et al., 1992).

On a theoretical level, our results can be explain in terms of the central capacity sharing model (Tombu & Jolicoeur, 2003). As predicted there, the stage of response selection, in cases with very short or no stimulus onset asynchrony (SOA) between task A and task B, causes central processing overlap, which demands the sharing of available resources for both tasks. This cause slow-down in processing of task A compared to the cases where there is only a single task to perform, or SOA between task A and task B is long enough that A finishes central processing before B. This effect, should not appear according to central bottleneck model (Pashler, 1994). Here, at short SOAs task B is waiting for task A to finish bottleneck processing, however the RTs for task A should not be affected despite of task B appearance. In our experiment a general slow-down appeared when comparing the reaction times for the primary task performed within a single task trial vs. dual-task trials (see figure 1), which means that color naming task partially shared central resources with tone discrimination task. Additionally, we can observe that the process is qualified by the level of control, which reduces the adaptation costs (i.e. response selection) to dual-task if performed after another high-control demanding task. Looking at the differences in time needed to perform secondary-tasks we can draw the conclusion that higher control activation improves the response selection process and by this reduce time of secondary task performance (see figure 3). Overall, these findings confirm the literature on conflict adaptation and hence support our hypothesis that dual-task interference is resolved by the same conflict monitoring/control mechanism as the other often postulated executive control functions.

Experiment 2

Experiment 1 showed increased top-down behavioral adjustment after resolving a dual-task. It should be noted that both the primary and secondary tasks used in Experiment 1 are discrete tasks in the sense that information processing only occurs between the stimulus and response. As shown by our additional analysis, participants mainly responded to both tasks in a sequential fashion – first to the color of the letter string first and then to the tone. This required minimal dual-task demands. The goal of Experiment 2 was to extend the results from Experiment 1 by using a primary task that imposes a continuous cognitive load, through which concurrent processing demands are maximized. To this end, we used an n-back updating task (e.g. Owen et al., 2005). The n-back task requires participants to decide whether each stimulus in a sequence matches the one that appeared *n* items ago (e.g. Owen, McMillan, Laird & Bullmore, 2005). An example of a 1-back match for the letter string F-*B*-*B*-L is when *B* appears two times in a row, and an example of a 2-back match is F-*B*-L-*B*. A 2-back mismatch would be F-B-L-F. Subjects are required to remember a specified number (*n*) of the most recently presented items in serial order (*n*-back). While the task evolves and new items are presented, the subjects have to update the memorized string of n most recent items: they need to unbind the oldest item and bind the most recent one to a position in working memory. To correctly perform the *n*-back task participants have to hold and manipulate information between trials, hence strongly relying on executive control functions located in the prefrontal cortex (PC) (Kane, Conway, Miura & Colflesh, 2007; Owen et al., 2005; Rodriguez-Jimanez, Avila, Garcia-Navarro, Bagney, Aragon, Ventura-Campos, Martinez-Gras, Forn, Ponce, Rubio, Jimenez-Arriero & Palomo, 2009). In this experiment the dual-task procedure required participants to respond to different stimuli (auditory and visual, as in Experiment 1) but also to maintain and update information from trial to trial. So the primary task was a 1-back task. In some of the trials (50% of total trials) a tone appeared and participants also had to respond if this tone had a high or low pitch. As in the previous experiment, we predicted that the conflict effects (i.e. dual-task interference effect) would be reduced if followed by a conflict trial (dual-task) relative to being followed by another non-conflict trial (single-task).

Method

Subjects

Twenty two undergraduate students (12 female and 10 male) from the University of Social Sciences & Humanities participated in the experiment. They received credit points for their participation. The data of two participants were excluded (1M and 1F), as more than 30% of their reactions were recorded as "no-response".

Apparatus and stimuli presentation settings

We used the same apparatus and stimuli settings as in experiment 1.

Materials and procedure

The primary task was a 1-back memory updating task, with 18 randomly chosen letters from the Latin alphabet. Additionally, a high or low tone was presented along with the letter in the dual task situation. Instructions with sample presentations were given on a computer screen at the beginning of the experiment. Each subject was presented with 2 blocks of trials (144 trials in total), separated with short, 30 second rest periods. The list of trials in each block contained 36 match trials (i.e. letter matched the letter presented 1 position before) and 36 mismatch trials (i.e. letter did not match the letter presented 1 position before). 50% of trials were dual task trials with the additional requirement of tone discrimination. Before starting the main experimental blocks participant performed 16 warm-up 1-back trials, with feedback provided if their answers were correct or incorrect.

The sequence of events on each trial was as follows: A letter was displayed for 500ms, with tone presented simultaneously for dual task trials. After the letter disappeared, participants were given 3000ms to respond, after which the next trial began. A lack of response within this time was recorded as "no-response". Responses were provided with feedback - small crosses appeared on the screen to assure participants that their reaction was recorded. Both correct and error responses were recorded. Response times were recorded relative to the onset of the stimulus.

Results

As previously, analyses were conducted on mean reaction times for correct responses on the primary task (i.e. 1-back task) and error rates. The data were analyzed with 2x2 repeated measure ANOVA, with type of trial (S vs. D) and type of the previous trial (s vs. d) as independent variables.

The analyses revealed similar effects as in experiment 1. As illustrated on figure 4 the main effect of type of trial was significant, showing that in general responses to the primary task in dual-task trials were slower (M_D = 1092 ms, SD = 269) than in single trials (M_S = 1023 ms, SD = 298): $F(1,19)$ = 15.38, $p < .01$, η^2 = .45. As previously, these differences occurred for both types of previous trial conditions: if the previous trial was single (M_{sD} = 1038 ms, SD = 224 vs. M_{sS} = 956 ms, SD = 261), $F(1,19)$ = 13.71, $p < .01$, η^2 = .42, as well as if the previous trial was dual (M_{dD} = 1145 ms, SD = 314 vs. M_{dS} = 1089 ms, SD = 336), $F(1,19)$ = 14.34, $p < .01$, η^2 = .43. Additionally, the main effect of previous trial type occurred, as primary-task responses appearing after single trials were performed faster than those after dual trials (M_s = 967 ms, SD = 242 vs. M_d = 1117 ms, SD = 325): $F(1,19)$ = 17.69; $p < .001$, η^2 = .48. Again, these effects were qualified by the nature of the relation between the current and previous trials and resulted in a trend level interaction: $F(1,19)$ = 3.89, $p = .06$, η^2 = .17. Thus single trials produced longer response times if they appeared after a dual trial (M_{dS} = 1089 ms, SD = 336) than after a single trial (M_{sS} = 956 ms, SD = 261): $F(1,19)$ = 19.91, $p < .001$, η^2 = .51. There was also a significant difference for dual task trials, though smaller in size (M_{sD} = 1038 ms, SD = 224 vs. M_{dD} = 1145 ms, SD = 314): $F(1,19)$ = 13.78, $p < 0.01$, η^2 = .42.

Figure 4 here

Analysis of errors (figure 5) showed a significant main effect of type of previous trial: $F(1,19)$ = 26.32, $p < .001$, η^2 = .58. Trials performed after dual-task trials were more accurate than trials performed after single-task (M_d = .14, SD = .14 vs. M_s = .24, SD = .12). There was also a main effect for type of current trial, $F(1,19)$ = 10.39, $p < .01$, η^2 = .35, indicating that single trials were more accurate than dual trials (M_D = .13, SD = .12 vs. M_S = .16, SD = .14). Lastly, there was a significant interaction: $F(1,19)$ = 36.45, $p < .001$, η^2 = .66. This was caused by the relatively low accuracy of dual trials performed right after single trials (M_{sD} = .31, SD = .09) as compared to dual trials performed after another dual trial (M_{dD} = .14, SD = .13), $F(1,19)$ = 65.52, $p < .001$, η^2 = .78, and compared to single trials performed after another singe trial (M_{sS} = .17, SD = .14), $F(1,19)$ = 41.79, $p < .001$, η^2 = .69.

Figure 5 here

As in Experiment 1, we checked for task prioritization in dual-task trials and found that in 88.4% (SD=18.9%) of all dual trials the n-back task was performed as the primary task and tone discrimination as the secondary. A 2x2 repeated measure ANOVA (type of task: primary vs. secondary x type of previous trial: single vs. dual) revealed a significant main effect of task type: $F(1,19) = 13.12$, $p < .001$, $\eta^2 = .41$ – see figure 6. Time needed to respond to the primary n-back task was greater than to the secondary tone discrimination task ($M_{\text{Prim}} = 1085$ ms, $SD = 269$ vs. $M_{\text{Sec}} = 787$ ms, $SD = 337$). We also found a significant interaction of factors: $F(1,19) = 6.94$, $p < .05$, $\eta^2 = .27$. As in experiment 1, time needed to respond to the primary task when it was performed after a single trial ($M_{Prim\text{-}sing} = 1038$ ms, $SD = 224$) was shorter than after another dual trial ($M_{Prim\text{-}dual} = 1145$ ms, $SD = 314$), $F(1,19) = 13.78$, $p < .01$, $\eta^2 = .42$, while the response lag for the secondary task was at a trend level of significance ($M_{Sec\text{-}dual} = 730$ ms, $SD = 175$ vs. $M_{Sec\text{-}sing} = 774$ ms, $SD = 177$), $F(1,19) = 3.09$, $p = .08$, $\eta^2 = .14$).

Figure 6 here

Discussion

The goal of Experiment 2 was to investigate whether the conflict monitoring/control mechanism can be deployed to adapt to interference in dual-tasking when the primary task also imposes a continuous load on working memory. The results support our main hypothesis, in the sense that a Gratton-like conflict adaptation effect (Gratton et al., 1992) was observed. The conflict effect was larger under conditions of low top-down control, i.e. when the previous trial was non-conflict (single), than under conditions of higher top-down control, i.e. when the previous trial was conflict. We again observed improvement of the response selection process, which resulted in overall better coping with task overlap. However, it is worth noting the differences between the results obtained in experiments 1 and 2. While the response times and error patterns for the dual-task was similar in both experiments, the exact

response times for the secondary task were longer in experiment 2 even though the task was the same, e.g. tone discrimination. Time measured for the primary task response was 451 ms (SD = 199) in Experiment 1 and 791 ms (SD = 307) in Experiment 2 (t(38) = 4.16, p < .001). This may be due to the higher control and resource demands of the 1-back working memory updating task relative to the less demanding color-naming task used in Experiment 1. This again stands in line with predictions from the Central Capacity Sharing Model (Tombu & Jolicœur, 2003), as more demanding tasks increase the time that tasks are shared in central processing. Taking this together with the accuracy data, we can see that the state of lower top-down control appears in this case only after repeated single-trials, resulting in relatively fast responses but a higher error rate. This again suggests that the state of higher control, which is obtained after performing dual-task, improves the process of response selection on the next trial, as response representation are activate and available for central resources. Altogether, these findings show that increased control reduced the conflict through top-down adaptation, but the exact behaviors that lead to this conflict reduction depend on the nature of the primary and secondary tasks.

Conclusion

The main goal of the current study was to investigate whether conflict adaptation mechanisms, as described by the Conflict Monitoring Hypothesis, also underlie dual-tasking. We based our expectations on the assumption that there are similarities between the interference occurring in traditional conflict tasks (e.g. Stroop task or flanker task) and dual-task interference. Across two experiments we provided evidence that decreased cognitive control after a single task resulted in high conflict effects when a secondary task appeared. This can be understood as a state of low top-down regulation in which the monitor and regulative system are not triggered to resolve the interference because the interference is scarce. By contrast, an increased top-down regulation after dual-task trials reduces the conflict in information processing while also slowing down performance overall.

Despite the observed similarities, a few differences must be underlined here. In the case of conventional conflict or interference tasks, interference is understood as a competition between an automatic and a controlled process (like word reading and color naming in the Stroop task). In dual-task coordination, when the processing of two stimuli that belong to two different tasks is required, competition arises between the processing of Task A and Task B,

causing so-called dual-task interference (see. Pashler, 1994; Monsell, 2003). It is worth mentioning that there are also differences between the resolution of dual-task interference and Stroop-like interference. In traditional conflict tasks, top-down adaptation means attending to and prioritizing processing of the relevant dimension of the task, while ignoring the irrelevant dimension. In a dual-task setting, however, both response "dimensions" are relevant, which means that top-down behavioral adjustments are more strategic in the sense that they deal with the bottleneck limitations and tasks competition for central resources (McCann & Johnston, 1992; Lien, Ruthruff & Johnston, 2006). What is usually observed is that the central resources are at least partially shared at the stage of response selection and thus a cognitive slack appears before the secondary task response selection can be completed. However, our experiments showed that increased cognitive control reduces the slack period and improves performance accuracy, while also slowing down the overall performance of both the primary and secondary task. Results confirm reduced conflict adaptation (Gratton-like effect) to secondary task if followed after another conflict task.

The bottleneck models postulates that bottleneck stages are responsible for response selection and decision making, while early processing is responsible for stimulus identification and late processing is responsible for response execution. The early and late stages can act on several stimuli simultaneously and can proceed simultaneously with bottleneck processing. In other words, stimulus identification and response execution can operate in parallel, whereas processors at or around response selection must operate on stimuli serially (Pashler, 1994) or share available resources (Tombu & Jolicœur, 2003). The results of our experiments suggests that higher top-down control organizes the "preapproval" of required responses and thus secondary task "bypassing" is less likely to appear (Maquestiaux, Lague-Beauvais, Ruthruff & Bherer, 2008; Tombu & Jolicœur, 2003). Comparing the differences in RT needed to respond to primary task (see figures 1 & 4) we can see that the task response is delayed by secondary task appearance – which suggest that central resources are partially shared by both tasks, as predicted by central capacity sharing model (see Tombu & Jolicœur, 2003). Moreover, taking into account RT's for secondary task (see figures 3 & 6) as well as the error rate data (see figures 2 & 5) we can conclude that the conflict adaptation is improving response selection process probably due to remaining activation of response representations for secondary task. In order to this the task become "less demanding" and the time both task share available central resources is reduced.

However, as to better understand which of the processes involved in dual task performance are optimized (e.g. attention allocation, response selection, or response strategy), future studies should include e.g. the manipulation of resource demands of the secondary task as well as the SOA interval. But as far as the current data are concerned, it seems that both types of adaptation (e.g. conflict and dual-task) are achieved through an executive control mechanism.

This behavioral study provides evidence for Gratton-like conflict or interference adaptation effects in the context of dual-task performance. It suggests that demonstration of the Gratton effect is not restricted to tasks where controlled processing is required to respond only to the relevant features of stimuli while ignoring those that are irrelevant. Taking this along with previous studies on working memory updating (Szmalec, Verbruggen, Vandierendonck & Kemps, 2011), we argue that the control mechanism behind the Gratton effect seems to be a functionally adaptive mechanism of cognitive control that can administrate the way people perform multiple types of everyday tasks.

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