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Can executive control be influenced by performance feedback? Two experimental studies with younger and older adults

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Executive control describes a wide range of cognitive processes which are critical for the goal-directed regulation of stimulus processing and action regulation. Previous studies have shown that executive control performance declines with age but yet, it is still not clear whether different internal and external factors—as performance feedback and age—influence these cognitive processes and how they might interact with each other. Therefore, we investigated feedback effects in the flanker task in young as well as in older adults in two experiments. Performance feedback significantly improved executive performance in younger adults at the expense of errors. In older adults, feedback also led to higher error rates, but had no significant effect on executive performance which might be due to stronger interference. Results indicate that executive functions can be positively influenced by performance feedback in younger adults, but not necessarily in older adults.

Keywords: age differences, feedback, cognition, executive control

INTRODUCTION

Previous studies have shown that older adults perform poorly in executive control tasks as compared to younger controls (Andrés and van der Linden, 2000; Treitz et al., 2007). These performance deficits in the elderly are usually explained by age-related changes in the brain, especially in the frontal lobes. There is evidence that the prefrontal areas of the brain which are supposed to be involved in executive control are affected more than other parts of the brain during the course of aging (West, 1996; Raz, 2000; Tisserand and Jolles, 2003; Raz and Rodrigue, 2006). This assumption is known as the *frontal hypotheses of cognitive aging* (West, 1996; Raz, 2000). But although aging can accompanied by changes in the brain and cognitive decline, there is a large inter-individual variability due to differential aging effects and compensatory mechanisms (Salthouse, 1996; Deary and Der, 2005; Reuter-Lorenz and Lustig, 2005). For example, Salthouse (1996) found that many of the effects of age on cognition are mediated by age-related variance in processing resource variables.

One factor that has also been shown to modulate cognitive performance in the elderly is feedback. Providing participant's feedback about their performance seems to influence their subsequent performance. The influence of feedback has been studied in a variety of cognitive tasks, including different types of learning, decision-making, memory and meta-memory (e.g., Kulik and Kulik, 1988; Diehl and Sterman, 1995; Thompson, 1998; West et al., 2005; Butler and Roediger, 2008). Meta-analyzes indicate that feedback can have a positive effect on performance ranging from $d = 0.12$ to $d = 1.24$ (Kluger and DeNisi, 1996; Hattie and Timperley, 2007). It is suggested that the feedback effect mainly results from expanding more effort in terms of intensity and persistence (Locke and Latham, 1990). Feedback may thus have an influence on performance by allocating attentional resources to the task which is realized by the so-called executive control system. The question arises whether there is a performance conflict when a feedback intervention is combined with performing a task that also requires a substantial amount of executive control. According to the integrated resource allocation model proposed by Kanfer and Ackerman (1989, 1996), a person's performance is a joint function of his or her relative attentional capacity, task demands, and motivation. It is suggested that motivational interventions (e.g., giving performance feedback) have context-dependent effects on performance by increasing cognitive interference and attentional allocations to the task. The model would thus predict that a task that requires the exertion of executive control would interfere more with the processing of feedback than a task that does not require executive control. Nevertheless, previous studies investigating dual-task performance indicate that feedback has a positive influence on task performance (Kramer et al., 1995, 1999; Bherer et al., 2005, 2008). The findings suggest that despite the existing performance conflict that evolves when combining an executive control task with a feedback intervention, one is still able to profit from feedback. However, it should be noted that in complex tasks, the feedback effect seems to be smaller as compared to more simple tasks (for a review, see Kluger and DeNisi, 1996).

With regard to possible aging effects, it has been shown that performance feedback in memory tasks led to increased performance in older adults (Stadtlander and Coyne, 1990; West et al., 2005, 2009). West and colleagues (2005) demonstrated that objective feedback about the number of items remembered was sufficient to improve recall in older as well as younger adults. Moreover, feedback led to higher motivation and goal commitment with even stronger effects in older adults. Further evidence for the influence of feedback on performance was found in a time estimation task (Wild-Wall et al., 2009). Wild-Wall and colleagues found that older as well as younger adults had a higher probability to respond correctly after positive feedback as compared to negative feedback. In a recent study, Bherer and colleagues (2008) demonstrated that continuous individualized adaptive feedback led to improvement in dual-task performance in older as well as younger adults. This study indicated that not only memory can be influenced by feedback but also executive functions.

Results suggest that feedback has an impact on the performance of participants in different age groups. However, the effect might be attenuated in older adults as compared to younger adults (West and Thorn, 2001; West et al., 2001). This attenuation might be due to weakened phasic activity of the dopaminergic system in older adults which seems to be involved in feedback processing and the allocation of attentional resources (Nieuwenhuis et al., 2002; Wild-Wall et al., 2009). At first sight, this result (West and Thorn, 2001) seems to be contradictory to the above-mentioned results from West et al. (2005): on the one hand they found an attenuated feedback effect in older adults and on the other hand they found a positive performance change by older adults to a goal-condition that included objective feedback. West et al. (2005) hypothesized a reduced memory self-efficacy may lead the older adults to interpret a neutral or inconsistent feedback as negative which may result in poorer memory performance (West and Thorn, 2001; West et al., 2001).

The aim of the two present experiments was to investigate whether feedback has an influence on executive control performance and whether there are differential aging effects existing. We were interested if possible feedback effects found in younger participants can also be found in a group of elderly participants. As it is still unclear if performance feedback interacts with the degree of executive control or complexity involved in the task, we aimed to investigate in a first experiment if performance in a task involving executive control (i.e., flanker task) can be influenced by performance feedback. Therefore, we examined a group of younger participants with a typical executive control task (i. e., flanker task) and allocated them to a feedback and a no-feedback group, respectively. We hypothesized that feedback would improve task performance in young adults. Furthermore, we expected that feedback would interact with congruent and incongruent trials of the flanker task as they differ in complexity and the demand of executive control. In a second study, a large group of older adults was investigated to replicate the findings of the first study. Here again, we hypothesized feedback to have a positive influence on performance. Such a replication is of importance because aging has been associated with the deterioration of the brain especially in prefrontal areas known to be involved in executive control (e.g., West, 1996; Raz, 2000). As previous literature has shown that feedback in the elderly has an influence on cognitive tasks such as memory (West et al., 2005, 2009) or time estimation tasks (Wild-Wall et al., 2009), it can be hypothesized that feedback would influence executive control performance in the elderly as well. But as the processing of feedback itself requires the exertion of executive control, it is questionable if older adults are able to profit from feedback in an executive control task in the same way as younger adults. As older adults have been reported to use a more cautious criterion than younger adults, i.e., focusing on accuracy to the detriment of speed (Salthouse, 1979; Strayer and Kramer, 1994; Smith and Brewer, 1995), we hypothesized that performance feedback would have an influence on executive control in the elderly, but not at the expense of errors. Still, we expected an attenuated feedback effect in the elderly due to a deficit in allocating attentional resources (Tsang and Shaner, 1998; Nieuwenhuis et al., 2002; Wild-Wall et al., 2009). Since younger and older adults differ in many characteristics, a separate study was performed and analyzed. To enable a comparison of both studies, effect sizes (ES) were reported.

EXPERIMENT 1: INFLUENCE OF PERFORMANCE FEEDBACK ON FLANKER TASK PERFORMANCE IN YOUNGER ADULTS

The goal of the study was to examine context-dependent effects on performance in an executive control task, i.e., to test if performance in a task involving executive control (flanker task) can be influenced by performance feedback. To test this hypothesis we provided positive, negative as well as neutral performance feedback in a flanker task with congruent, incongruent, and neutral trials expecting feedback to interact with task complexity.

METHODS

PARTICIPANTS

A total of 46 young healthy students, 26 males and 20 females, with a mean age of 23.9 years (SD = 3.1) participated in this experiment. Participants were recruited by means of flyers distributed on the university campus. Half of the group performed the feedback version while the other half performed the no-feedback version of the paradigm. The allocation to the respective feedback group was completely randomized and there was no difference in age, sex, or handedness (all participants were right-handed) between both groups. Participants were informed about the objectives and procedure of the present study. The study protocol was approved by the local ethics committee and all subjects gave their written consent, participated voluntarily and were paid a small allowance.

MATERIALS AND DESIGN

A modified version of the flanker task was employed (e.g., Kopp et al., 1996). Participants were required to identify whether a central arrow presented on a computer screen pointed left or right by pressing the equivalent button on the keyboard with their preferred hand. Participants were asked to respond as quickly and accurately as possible. The target arrow was flanked on either side by two arrows in the same direction (congruent condition), or in the opposite direction (incongruent condition). As in the incongruent condition flanking stimuli point to the direction opposite to the target, this condition is more complex and requires more executive control than the congruent condition. In each trial, one central arrow accompanied by four flankers was presented. Targets and flankers appeared simultaneous. The two flanker conditions are depicted in **Figure 1**.

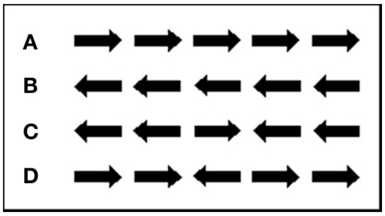

FIGURE 1 | The four target conditions of the flanker task: (A) congruent condition, target right, (B) congruent condition, target left, (C) incongruent condition, target right, (D) incongruent condition, target left.

Participants performed one baseline block followed by nine experimental blocks with 40 trials each, resulting in 360 experimental trials altogether. Half of the trials were congruent, half were incongruent, resulting in a total of 180 congruent and 180 incongruent trials. The ratio of targets pointing to the left and pointing to the right was also balanced.

Participants were randomly allocated into two groups: the feedback group and the no-feedback group. The feedback group received performance feedback which was presented on the computer screen after each block displaying the mean reaction time (RT in milliseconds) of the preceding block of trials. In addition, mean RTs of all preceding blocks were presented to inform participants about the course of their performance. The no-feedback group received no performance feedback. The words "rest period" were presented on the screen after each block. Participants were required to press a button after each block to start the next block of trials.

The stimuli were placed in the center of the screen, subtending a visual angle of 2.86° horizontally and 0.24° vertically. In each trial, a fixation cross was first presented for 900–2100 ms. The target arrow with flankers was then shown up to 2000 ms in the baseline block and for the duration of an individually computed reaction time window in the experimental blocks, respectively. After a response, the fixation cross was presented and the next trial started. An individual response window was calculated for each participant to force speeded responses and to make the task more difficult. The individual response window was determined by adding one standard deviation to the mean reaction time in the baseline block.

PROCEDURE

Participants first completed a health questionnaire after a verbal instruction of the investigator. No participant had to be excluded because of health status and there was no history of neurological or mental disorder. While participants were seated approximately 60 cm in front of a computer screen, the experiment was conducted using the presentation software package (Neurobehavioral Systems, San Francisco, CA). Participants were instructed to respond as quickly and accurately as possible.

Before the flanker task was performed, participants carried out a practice block with 10 trials which they were allowed to repeat until they were familiar with the task. During the practice block, participants received feedback whether their response was correct or incorrect. After each experimental block, one group received feedback about their mean reaction time (feedback group) while the other group received no-feedback (no-feedback group). Total duration of the flanker task was about 20–30 min depending on the individual response window and the duration of self-paced rest periods between the blocks.

STATISTICAL ANALYSIS

For data analysis, only valid trials and trials with a reaction time between 200 and 2000 ms were considered. In addition, an individual outlier analysis was performed. Trials with a reaction time two standard deviations above the condition mean were not considered. For further analysis of error percentage only response errors (i. e., pushing the wrong button) were considered. Omission errors were not included because there were two types of error coded in this variable (no response at all and no response within the reaction time window, respectively). As an additional variable the congruency effect was computed which is a measure of executive control. It is defined as the difference between reaction time or errors in congruent and incongruent trials (Nieuwenhuis et al., 2006). A small difference indicates better conflict resolution and thus better executive control. Two repeated measures ANOVAs with congruency as within-subjects factor and feedback as between-subjects factor were calculated. As dependent variables, reaction times as well as response error percentage were analyzed and Greenhouse-Geisser F-values are reported. Additionally, ES bias-corrected according to Hedges (Hedges and Olkin, 1985) and 95% confidence intervals (CI) were calculated.

RESULTS

REACTION TIMES

Results of the repeated measures ANOVA with reaction times as dependent variable revealed that feedback had a significant influence [$F_{(1, 44)} = 5.35$, $p = 0.025$] on reaction times. Participants receiving feedback showed faster responses ($M = 391$ ms, SD = 28 ms) than participants without feedback ($M = 406$ ms, SD = 22 ms; ES = 0.62, CI = 0.02–1.21). Furthermore, there was also a congruency effect [$F_{(1, 44)} = 298.96$, $p < 0.001$]. As expected, incongruent trials elicited slower responses ($M = 410$, SD = 27) than congruent trials ($M = 384$, SD = 24; ES = 1.01, CI = 0.58–1.44). The Interaction between congruency and feedback was marginally significant [$F_{(1, 44)} = 3.91$, $p = 0.054$]. The congruency effect was smaller in the feedback group ($M = 23$ ms, SD = 12) as compared to the no-feedback group ($M = 29$ ms, SD = 9; ES = 0.56, CI = −0.03–1.14). When calculating the relative congruency effect which considers percental change, results are in line showing a smaller effect for the feedback group ($M = 6.1\%$, SD = 3.0) as compared to the no-feedback group ($M = 7.5\%$, SD = 2.3; ES = 0.50, CI = 0.08–0.91). **Table 1** provides an overview of all variables.

ERROR PERCENTAGE

Analyzes of error percentage as dependent variable showed a significant influence of feedback on errors [$F_{(1, 44)} = 11.16$, $p < 0.005$], but reversely to reaction times. The feedback group committed relatively more errors ($M = 4.3$ %, SD = 3.3) than the no-feedback group ($M = 1.8$ %, SD = 1.4; ES = 0.97,

Table 1 | Arithmetic mean (M) and standard deviation (SD) of ExFuNet variables for feedback (FB) vs. no-feedback group (noFB) for younger adults.

	FB $N = 23$		No-FB $N = 23$		All participants $N = 46$	
	M	**SD**	***M***	**SD**	***M***	**SD**
Overall RT (ms)	391	28	406	22	399	26
Congruent RT (ms)	377	26	390	20	384	24
Incongruent RT (ms)	400	30	419	20	410	27
Congruency effect (ms)	23	12	29	9	26	11
Relative effect (%)	6.1	3.0	7.5	2.3	6.8	2.8
Response Errors (%)	4.3	1.8	1.4	3.1	3.1	2.8
Congruent Errors (%)	2.1	1.9	0.8	0.7	1.4	1.4
Incongruent Errors (%)	6.5	5.3	2.9	2.5	4.7	4.5
Congruency effect (%)	4.4	4.6	2.1	2.4	3.3	3.8
Overall accuracy (%)	86.2	4.5	87.7	5.1	87.0	4.8

CI = 0.36–1.58). In addition, there was also a congruency effect [$F_{(1,\ 44)} = 37.45$, $p = < 0.001$]. More errors were made during incongruent trials ($M = 4.7$ %, SD = 4.5) than during congruent trials ($M = 1.4$ %, SD = 1.4; ES = 0.98, CI = 0.55–1.41). The interaction between congruency and feedback was also significant [$F_{(1,\ 44} = 4.85$, $p < 0.05$]. Contrary to reaction times, the congruency effect in error percentage was larger in the feedback group ($M = 4.4$ %, SD = 4.6) as compared to the no-feedback group ($M = 2.1$ %, SD = 2.4; ES = 0.62, CI = 0.02–1.21).

EXPERIMENT 2: FEEDBACK EFFECT IN OLDER ADULTS

Experiment 1 provides initial support for the hypothesis of an interaction between task complexity (congruency) and feedback. Experiment 2 was designed to replicate the findings of the first experiment for older participants to detect a possible interaction between aging, task complexity and feedback.

METHODS

PARTICIPANTS

A total of 168 healthy elderly persons, 82 males and 86 females, with a mean age of 70.5 years (SD = 7.1) participated in this experiment. Participants were recruited by a press report in the local newspapers as well as by the means of flyers. They had a mean education of 13.4 years (SD = 3.6). Of all participants, 157 were right-handed, seven were left-handed, and four were ambidexter. Participants were randomly assigned to a feedback and a no-feedback group resulting in 84 participants in each group. Both groups did not differ in age, sex, and handedness. There was a significant difference [$T_{166} = 2.58$, $p < 0.05$; ES = 0.40, CI = 0.09–0.70] in years of education as the no-feedback group had more years of education ($M = 14.1$, SD = 3.7) than the feedback group ($M = 12.7$, SD = 3.4). The difference in education years had no impact on the results obtained as there were no correlations between this variable and performance in the flanker task. All participants were informed about the objectives and procedure of the present study. The study protocol was approved by the local ethics committee and all subjects gave their written consent, participated voluntarily and were paid a small allowance.

MATERIALS AND DESIGN

See Experiment 1

PROCEDURE

See Experiment 1

STATISTICAL ANALYSIS

See Experiment 1

RESULTS

REACTION TIMES

Results reveal that feedback had no significant influence on reaction times [$F_{(1,\ 166)} < 1$, $p = 0.85$]. The slightly faster reaction times of the feedback group ($M = 515$ ms, SD = 51) did not differ from those of the no-feedback group ($M = 523$ ms, SD = 55; ES = 0.15, CI = −0.15–0.45). Congruency had a significant influence [$F_{(1,\ 166)} = 456.8$, $p < 0.001$] on reaction times. As expected, incongruent trials elicited slower responses ($M = 533$ ms, SD = 55) than congruent trials ($M = 507$ ms, SD = 52; ES = 0.48, CI = 0.27–0.70). The interaction between congruency and feedback did not reach significance [$F_{(1,\ 166)} = 1.29$, $p = 0.40$]. There was no difference between the congruency effect in the feedback group ($M = 25$ ms, SD = 15) and the no-feedback group ($M = 28$ ms; SD = 17; ES = 0.19, CI = −0.49–0.12). The same result is obtained when calculating the relative congruency effect (percental change) which also shows no difference between the feedback group ($M = 5.1$%, SD = 3.1) and the no-feedback group ($M = 5.5$%, SD = 3.2; ES = 0.14, CI = −0.07–0.35). **Table 2** provides an overview of all variables.

Furthermore, we calculated a another analysis of variance with the same factors as above and the additional factor "graduation" as the feedback and the no-feedback group differed in their education (see Methods). Results showed a significant main effect of graduation [$F_{(1,\ 166)} = 13.6$, $p < 0.01$] but no significant

Table 2 | Arithmetic mean (M) and standard deviation (SD) of ExFuNet variables for feedback (FB) vs. no-feedback group (noFB) for older adults.

	FB $N = 84$		No-FB $N = 84$		All participants $N = 168$	
	M	**SD**	***M***	**SD**	***M***	**SD**
Overall RT (ms)	515	51	523	55	519	53
Congruent RT (ms)	504	51	510	53	507	52
Incongruent RT (ms)	529	52	538	57	533	55
Congruency effect (ms)	25	15	28	17	26	16
Relative effect (%)	5.0	3.1	5.5	3.2	5.2	3.2
Response Errors (%)	2.5	2.1	1.8	1.8	2.2	2.0
Congruent Errors (%)	1.8	1.9	1.3	1.8	1.6	1.8
Incongruent Errors (%)	3.2	2.9	2.3	2.1	2.8	2.6
Congruency effect (%)	1.4	2.3	1.0	1.7	1.2	2.1
Overall accuracy (%)	93.1	3.9	93.1	4.0	93.1	3.9

interaction effects and the overall pattern of results remains the same.

ERROR PERCENTAGE

Analysis of error percentage showed that feedback had a significant influence on error percentage [$F_{(1, 166)} = 5.3$, $p < 0.05$]. The feedback group ($M = 2.5\%$, SD = 2.1) committed more errors than the no-feedback group ($M = 1.8\%$, SD = 1.8; ES = 0.36, CI = 0.05–0.66). Congruency had also a significant influence on errors [$F_{(1, 166)} = 56.3$, $p < 0.001$]. More errors were committed during incongruent trials ($M = 2.8\%$, SD = 2.6) as compared to congruent trials ($M = 1.6\%$, SD = 1.8; ES = 0.54, CI = 0.32–0.75). Thus, although the feedback group did not significantly profit from feedback regarding reaction times, it showed an increase in errors. The interaction between congruency and feedback was not significant [$F_{(1, 166)} = 1.8$, $p > 0.05$]. There was no difference between the congruency effect in the feedback group ($M = 1.4\%$, SD = 2.3) as compared to the no-feedback group ($M = 1.0\%$, SD = 1.7; ES = 0.20, CI = −0.11–0.50).

GENERAL DISCUSSION

The first study examined the influence of performance feedback on executive control in young adults. Results indicated that feedback had an influence on both reaction times and errors in the flanker task. The feedback group responded faster than the no-feedback group, but this reaction time improvement was at the expense of errors which points to a feedback-induced speed-accuracy trade-off (e.g., Luce, 1986). However, the speed-accuracy trade-off is not surprising as feedback was only provided about reaction times and not about errors. Therefore, participants focused on faster reaction times rather than accuracy. A second important finding was that feedback had a positive influence on executive control performance which was reflected in the smaller congruency effect in reaction times. This finding indicates that although more attentional resources are required to perform the incongruent trials of the task, there is still the possibility of improving the exertion of executive control due to the feedback intervention. As participants focused on reaction times, the better executive control performance was at the expense of errors which was reflected in a higher congruency effect in errors.

Taken together, younger adults were able to adjust their attentional resources accordingly and showed faster responses in flanker task performance as well as a smaller congruency effect. This result is in line with Bherer and colleagues (2008) who investigated the influence of feedback on dual-task performance. Results of their study showed that feedback had an influence on a dual-task despite the fact that the task itself required the exertion of executive control.

In the first experiment it can be inferred that participants receiving feedback on reaction times allocated their attention resources accordingly and focused on speed only. This resulted in a feedback-induced shift in the speed-accuracy trade-off. One could speculate that feedback caused a shift toward a more risky criterion resulting in a higher number of errors. Support for this speculation is provided by a study carried out by Brébion (2001) who demonstrated that the instruction to focus on speed, not on accuracy, led to a shift in response criterion. Because in our study feedback was provided about reaction times, participants focused on speed at the expense of errors which may have resulted in a shift of the response criterion.

According to the integrated resource allocation model (Kanfer and Ackerman, 1989, 1996), a task that requires executive control interferes more with the processing of feedback than a non-executive control task. Results of the present study showed that even in an executive control task such as the flanker task performance feedback had a significant positive influence. The question remains if the feedback effect would have been larger in case a non-executive control task was employed.

In conclusion, it was shown that performance feedback had an impact on the flanker task including the congruency effect which supports the hypothesis that executive control can be positively influenced by performance feedback. In young adults, performance feedback can thus be applied to improve executive control performance.

The second experiment examined if the feedback effects on flanker task performance found in younger adults in Study 1 can be replicated in a group of older adults. Results indicated that feedback had an influence on errors, but not on reaction times. The feedback group committed more errors as compared to the no-feedback group, but did not respond faster. Although participants were not able to increase their reaction times with feedback, the increase in error rates indicates that older adults attempted to regulate their behavior according to the task, but failed in doing so. This might be due to older adults' deficits in allocating attentional resources to the task (Tsang and Shaner, 1998; Nieuwenhuis et al., 2002; Wild-Wall et al., 2009) which requires the exertion of executive control.

Results are in line with previous accounts reporting deficits in executive control performance in older adults (Andrés and van der Linden, 2000; Treitz et al., 2007) and with the notion that especially prefrontal brain areas supposed to be involved in executive control are affected during the course of aging (West, 1996; Raz, 2000; Tisserand and Jolles, 2003; Raz and Rodrigue, 2006).

It can be speculated that older adults already reached their performance limit because of the executive control requirements of the flanker task itself, and failed in speeding up their performance. This result is mirrored by the lack of an interaction between feedback and congruency for reaction times as well as for errors. As older adults reached their resource limit in performing the flanker task, feedback had no further impact on executive control performance in older adults as measured by the congruency effect. Despite helping to improve performance, feedback seems to have distracted participants away from the task. Together with Tsang and Shaner (1998) we speculate that adults experience a decreased flexibility in resource allocation.

Taken together, results support our hypothesis that performance feedback has an influence on flanker task performance in the elderly. However, older adults did not profit from feedback and feedback had no influence on executive control performance. As the flanker task itself required the exertion of executive control, it appears to have interfered with feedback processing resulting in performance decline. This is in accordance with the integrated resource allocation model (Kanfer and Ackerman, 1989, 1996) which predicts that motivational interventions increase cognitive interference. Results indicate that in older adults, performance feedback cannot be used to improve executive control performance as measured by the flanker task.

The aim of the present studies was to investigate if performance feedback has an impact on executive control and if feedback effects can equally be found in younger as well as older adults. Regarding younger adults, it could be shown that even in a task that requires the exertion of executive control, participants can profit from performance feedback which was shown in faster reaction times. Furthermore, feedback in younger adults had an influence on the congruency effect indicating better executive control regarding reaction times. Thus, it can be inferred that performance feedback in younger adults can be used to influence the exertion of executive control. Younger adults were able to speed up their reaction times after receiving performance feedback although the faster responses were accompanied by higher error rates. It is unlikely that this was due to the difficulty of the executive control task itself as the phenomenon of a speed-accuracy trade-off has been shown for a variety of non-executive control tasks as well (e.g., Kounios et al., 1994; Ratcliff, 2002; Ratcliff and Rouder, 2000; Rinkenauer et al., 2004).

Concerning older adults, we found an influence of feedback on error rates as well. However, the higher error rate was not accompanied by reaction time improvement as in younger adults. Thus, the feedback effect in older adults was attenuated probably due to stronger interference between the executive control task and the feedback intervention as predicted by the integrated resource allocation model (Kanfer and Ackerman, 1989, 1996). It seems most likely that older adults reached their resource limit in performing the flanker task and thus were not able to decrease their reaction times according to the feedback intervention. The fact that the feedback group shows a slight, but insignificant reaction time gain (8 ms; $ES = 0.15$) supports this interpretation.

Nevertheless, older adults showed a feedback-induced increase of errors which indicates that they tried to focus on improving speed at the expense of errors. Similar results were obtained in the above-mentioned study carried out by Brébion (2001) where it was found that older adults were able to shift their response criterion toward a more risky criterion when instructed to focus on speed only. It was reported that older adults still remained slower and a little more accurate than younger adults. This result could not be attributed to a more cautious strategy which is why it was concluded that older adults have a slower processing system. As previous studies have shown that older adults especially display deficits in executive control performance (Andrés and van der Linden, 2000; Treitz et al., 2007) which might be due to the deterioration of the brain in areas involved in executive control (West, 1996; Raz, 2000; Tisserand and Jolles, 2003; Raz and Rodrigue, 2006), it can be speculated that older adults have a less flexible processing system resulting in difficulties in allocating attentional resources appropriately (Tsang and Shaner, 1998; Nieuwenhuis et al., 2002; Wild-Wall et al., 2009).

It can be argued that there was no significant gain in reaction time in older adults because those already operating on their reaction time limit were not able to further speed up their reaction time. But when dividing the elderly sample into those with relatively fast and those with slow reaction times, no difference can be found regarding the influence of feedback. It can also be claimed that education might have an influence on the ability to profit from feedback as the younger participants in the first study were all students. Therefore, we analyzed a subgroup of elderly participants with a relatively high educational level (at least 12 years of school education) separately revealing the same pattern of results. Another important aspect between the two populations (younger vs. older participants) is their familiarity with playing games on a computer. The younger group might be more familiar with computerized games as many games basically use a structure where feedback is provided and fast responses are required whereas the older adults are likely to spend far less time playing computer games. As we cannot rule out that familiarity with computer games might have an influence on our results this factor should be considered in future studies investigating feedback effects. However, it cannot be ruled out that the low frequency of the feedback intervention (after each block) and the relatively neutral presentation of feedback (reaction times instead of direct negative and positive feedback) were not enough to activate a significant influence of feedback in the elderly. We also cannot exclude the possibility that differences in feedback evaluation may have had an influence on our findings (Kluger and DeNisi, 1996). Some participants may have evaluated the performance feedback as a slightly negative feedback; some might have evaluated the feedback as positive in case their reaction times improved from block to block. Against these arguments remains the fact that younger participants showed significant feedback effects and interactions.

Taken together, it was shown that performance feedback of reaction times had an influence on flanker task performance in younger as well as older adults. While in younger adults a functional feedback effect was found (i.e., faster responses); in older adults the effect was dysfunctional (i.e., no difference in reaction times between the feedback and the no-feedback group). Moreover, feedback had also an influence on the exertion of executive control as measured by the congruency effect in younger adults which indicates that in this age group performance feedback can be used to improve executive control.

It can be concluded that performance feedback not necessarily has a positive influence on executive control performance and that age should be considered when applying feedback interventions. Future studies concerning different sorts of feedback interventions with higher frequencies and stronger valence are needed to clarify the conditions under which older adults may or may not profit from feedback in tasks that require executive control.

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