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
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 (Salhouse, 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 simultaneously. The two flanker conditions are depicted in **Figure 1**.
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**
Analyze 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,
PARTICIPANTS

A total of 168 healthy elderly persons, 82 males and 86 females, with a mean age of 70.5 years (SD = 3.6) participated in this experiment. Participants were recruited by a press report in the local newspapers as well as 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 $[T_{166} = 2.58, p < 0.05; \text{ES} = 0.40, \text{CI} = 0.09–0.70]$ in years of education as the no-feedback group had more years of education ($M = 14.1, \text{SD} = 3.7$) than the feedback group ($M = 12.7, \text{SD} = 3.4$). 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 ($M = 515, \text{SD} = 51$) did not differ from those of the no-feedback group ($M = 523, \text{SD} = 55$; $\text{ES} = 0.15, \text{CI} = -0.15–0.45$). Congruency had a significant influence $[F(1, 166) = 456.8, p < 0.001]$ on reaction times. As expected, incongruent trials elicited slower responses ($M = 533, \text{SD} = 55$) than congruent trials ($M = 507, \text{SD} = 52$; $\text{ES} = 0.48, \text{CI} = 0.27–0.70$). The interaction between congruency and feedback did not reach significance $[F(1, 166) = 0.62, p < 0.02–1.21]$.

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 = 3.6) participated in this experiment. Participants were recruited by a press report in the local newspapers as well as 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 $[T_{166} = 2.58, p < 0.05; \text{ES} = 0.40, \text{CI} = 0.09–0.70]$ in years of education as the no-feedback group had more years of education ($M = 14.1, \text{SD} = 3.7$) than the feedback group ($M = 12.7, \text{SD} = 3.4$). 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

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

|                | FB            | No-FB          | All participants |
|----------------|---------------|----------------|------------------|
|                | $N = 84$      | $N = 84$       | $N = 168$        |
|                | $M$ | $SD$ | $M$ | $SD$ | $M$ | $SD$ |
| 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 Berther 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; Rinkenauger 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 Brebion (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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REFERENCES

Andrés, P., and van der Linden, M. (2000). Age-related differences in supervisory attentional system functions. J. Gerontol. Psychol. Sci. 55, P373–P380.

Bherer, L., Kramer, A. F., Peterson, M. S., Colcombe, S., Erickson, K., and Becic, E. (2005). Training effects on dual-task performance: are there age-related differences in plasticity of attentional control? Psychol. Aging 20, 695–709.

Bherer, L., Kramer, A. F., Peterson, M. S., Colcombe, S., Erickson, K., and Becic, E. (2008). Transfer effects in task-set cost and dual-task cost after dual-task training in older and younger adults: further evidence for cognitive plasticity in attentional control in late adulthood. Exp. Aging Res. 34, 188–219.

Breton, G. (2001). Language processing, slowing, and speed/accuracy trade-off in the elderly. Exp. Aging Res. 27, 137–150.

Butler, A. C., and Roediger, H. L. III. (2008). Feedback enhances the positive effects and reduces the negative effects of multiple-choice testing. Mem. Cogn. 36, 604–616.

Deary, I. J., and Der, G. (2005). Reaction time, age and cognitive ability: longitudinal findings from age 16 to 63 years in representative population samples. Aging Neuropsychol. Cogn. 12, 187–215.

Diehl, E., and Sterman, J. D. (1995). Effects of feedback complexity on dynamic decision making. Organ. Behav. Hum. Decis. Process. 62, 198–215.

Hattie, J., and Timperley, H. (2007). The power of feedback. Rev. Educ. Res. 77, 81–110.

Hedges, L. V., and Olkin, I. (1985). Statistical Methods for Meta-Analysis. Orlando, FL: Academic Press.

Kanfer, R., and Ackerman, P. L. (1989). Motivation and cognitive abilities: an integrative/aptitude-treatment interaction approach to skill acquisition. J. Appl. Psychol. 74, 657–690.

Kanfer, R., and Ackerman, P. L. (1996). “A self-regulatory skills perspective to reducing cognitive interference,” in Cognitive Interference: Theories, Methods, and Findings, eds I. G. Sarason, B. R. Sarason, and G. R. Pierce (Hillsdale, NJ: Erlbaum), 153–171.

Kluger, A. N., and DeNisi, A. (1996). The effects of feedback interventions on performance: a historical review, a meta-analysis, and a preliminary feedback intervention theory. Psychol. Bull. 119, 254–284.

Kopp, B., Rist, E., and Mattler, U. (1996). N200 in the flanker task as a neurobehavioural tool for investigating executive control. Psychophysiology 33, 282–294.

Kounios, J., Montgomery, E. C., and Smith, R. W. (1994). Semantic memory and the granularity of semantic relations: Evidence from speed-accuracy decomposition. Mem. Cogn. 22, 729–741.

Kramer, A. F., Larish, J. L., and Strayer, D. L. (1995). Training for attentional control in dual task settings: a comparison of young and old adults. J. Exp. Psychol. Appl. 1, 50–76.

Kramer, A. F., Larish, J. L., Weber, T. A., and Bardell, L. (1999). “Training for executive control,” in Attention and Performance XVII, eds D. Gopher and A. Koriat (Cambridge, MA: MIT Press), 617–652.

Kulik, J. A., and Kulik, C. I. (1988). Timing of feedback and verbal learning. Rev. Educ. Res. 51, 79–97.

Locke, E. A., and Latham, G. P. (1990). A Theory of Goal Setting and Task Performance. Englewood Cliffs, NJ: Prentice-Hall.

Luce, R. D. (1986). Response Times: Their Role in Inferfing Elementary Mental Organization. Oxford: Oxford University Press.

Nieuwenhuis, S., Riddervold, L., and Talsma, D. (2002). A computational model of altered error processing in older age: dopamine and the error-related negativity. Cogn. Affect. Behav. Neurosci. 2, 19–36.

Nieuwenhuis, S., Stins, J. F., Posthuma, D., Polderman, T. J., Boomsma, D. I., and de Geus, E. J. (2006). Accounting for sequential trial effects in the flanker task: conflict adaptation or associative priming? Mem. Cogn. 34, 1260–1272.

Ratcliff, R. (2002). A diffusion model account of response time and accuracy in a brightness discrimination task: Fitting real data and failing to fit fake but plausible data. Psychon. Bull. Rev. 9, 278–291.

Ratcliff, R., and Rouder, J.-N. (2000). A diffusion model account of masking in two-choice letter identification. J. Exp. Psychol. Hum. Percept. Perform. 26, 127–140.

Raz, N. (2000). “Aging of the brain and its impact on cognitive performance: Integration of structural and functional findings,” in Handbook of Aging and Cognition – II, eds F. I. M. Craik and T. A. Salthouse (Mahwah, NJ: Erlbaum), 1–90.

Raz, N., and Rodrigue, K. R. (2006). Differential aging of the brain: patterns, cognitive correlates and modifiers. Neurosci. Biobehav. Rev. 30, 730–748.

Reuter-Lorenz, P. A., and Lustig, C. (2005). Brain aging: reorganizing discoveries about the aging mind. Curr. Opin. Neurobiol. 15, 245–251.

Rinkenauer, G., Osman, A., Müller-Gethmann, H., and Mattes, S. (2004). On the locus of speed-accuracy trade-off in reaction time inferences from the lateralized readiness potential. J. Exp Psychol. Gen. 133, 261–282.

Saltzhouse, T. A. (1979). Adult age and the speed-accuracy trade-off. Ergonomics 22, 811–821.

Saltzhouse, T. A. (1996). The processing-speed theory of adult age differences in cognition. Psychol. Rev. 103, 403–428.

Smith, G. A., and Brewer, N. (1995). Slowness and age-speed-accuracy mechanisms. Psychol. Aging 10, 238–247.

Stadlander, L. M., and Coyne, A. C. (1990). The effect of goal-setting and feedback on age differences in secondary memory. Exp. Aging Res. 16, 91–94.

Strayer, D. L., and Kramer, A. F. (1994). Aging and skill acquisition: learning-performance distinctions. Psychol. Aging 9, 589–605.

Thompson, W. B. (1998). Metamemory accuracy: effects of feedback and the stability of individual differences. Am. J. Psychol. 111, 33–42.

Tisserand, D. J., and Jolles, J. (2003). On the involvement of prefrontal networks in cognitive ageing. Cortex 39, 1107–1128.

Tretiz, F. H., Heyder, K., and Daum, I. (2007). Differential course of executive control during normal aging. Aging Neuropsychol. Cogn. 14, 370–393.

Tsang, P. S., and Shaner, T. L. (1998). Age, attention, expertise, and time-sharing performance. Psychol. Aging 13, 323–347.

West, R. L. (1996). An application of prefrontal cortex function theory to cognitive aging. Psychol. Bull. 120, 272–292.

West, R. L., Bagwell, D. K., and Dark-Freudeman, A. (2005). Memory and goal setting: the response of older and younger adults to positive and objective feedback. Psychol. Aging 20, 195–201.

West, R. L., Dark-Freudeman, A., and Bagwell, D. K. (2009). Goals-feedback conditions and episodic memory: mechanisms for memory gains in older and younger adults. Memory 17, 233–244.

West, R. L., and Thorn, R. M. (2001). Goal-setting, self-efficacy, and memory performance in older and younger adults. Exp. Aging Res. 27, 41–65.

West, R. L., Welch, D., and Thorn, R. M. (2001). Effects of goal setting and feedback on memory performance and beliefs among older and younger adults. Psychol. Aging 16, 240–250.

Wild-Wall, N., Willemsen, R., and Falkenstein, M. (2009). Feedback-related processes during a time-production task in young and older adults. Clin. Neurophysiol. 120, 407–413.

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