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Aging and executive functioning: a training study on focus-switching

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Many studies suggest that age differences in a variety of cognitive tasks are due to age-related changes in executive control processes. However, not all executive control processes seem to be age-sensitive. Recently, Verhaeghen et al. (2005) described dissociable age effects in an executive control process responsible for the switching of representations between different functional units of working memory. This so called focus-switching process has two components: (1) the switching of representations from an activated part of long-term memory into a region of immediate access (focus of attention) and (2) the maintenance of representations outside the focus of attention. Age-related deficits occurred in maintaining representations outside the focus of attention, but were absent in switching representations into and out of the focus of attention (e.g., Dorbath and Titz, 2011). In the present study we applied a training approach to examine age-related differences in the trainability of maintenance and switching. We investigated 85 younger (age 19–35, $M = 24.07$, $SD = 3.79$) and 91 older (age 59–80, $M = 66.27$, $SD = 4.75$) adults using a continuous counting task in a pretest–training–posttest design. The participants were assigned to one of four training conditions differing in the demand to switch or to maintain. The results suggest the influence of training in both components of focus-switching for both, younger and older adults. However, age differences in the amount of training gains were observed. With respect to maintenance the results indicate a compensatory effect of training for older adults who improved their performance to the level of younger adults. With respect to switching, younger adults benefited more from training than older adults. Trainability is thus reduced in older adults with respect to switching, but not for maintenance.

Keywords: focus-switching, trainability, age effects, maintenance, switching, working memory

INTRODUCTION

An increasing amount of research has shown that aging is associated with progressive functional loss in many cognitive domains, including mental speed, episodic memory, and executive functioning (e.g., Hoyer and Verhaeghen, 2006; Craik and Salthouse, 2008). Current theories postulate that a decline in a limited number of basic executive control processes may account for the majority of these age differences (e.g., Hasher and Zacks, 1988; Mayr and Kliegl, 1993; Mayr et al., 2001). Consequently, interest was drawn in questions related to the modifiability of cognitive functions in general and specifically to the modifiability of executive control processes in adulthood. Especially cognitive interventions (e.g., Kramer and Willis, 2002) provide the opportunity to study age differences in cognitive trainability, that is the ability to improve one's performance through instruction and practice, and therefore the potential to maintain or to enhance cognitive performance in older age (Kramer and Willis, 2003; Bherer et al., 2005; Greenwood, 2007). The aim of the present paper is to study age-related dissociations in the trainability of a relatively new identified executive control process called focus-switching.

It is widely accepted that executive control, the ability to plan, guide, and monitor complex goal directed actions, consists of separate control components, such as task switching, coordination of distinct tasks or distinct processing streams, updating, and inhibition (resistance to interference; e.g., Kray and Lindenberger, 2000; Miyake et al., 2000; Fisk and Sharp, 2004; Huizinga et al., 2006). Verhaeghen and colleagues identified another basic control process that is distinct from the former executive processes operating on working memory, namely the focus-switching process (Verhaeghen and Hoyer, 2007; Verhaeghen et al., 2007). The existence of a focus-switching process can be deduced from Cowan's working memory model (Cowan, 1997, 2001). The model differentiates between a capacity-limited focus of attention and an outer store. In the focus of attention item representations can be accessed immediately. By contrast, representations outside the focus of attention are maintained in the outer store in a temporarily heightened state of activation without being immediately accessible and can be subject to interference and decay (Verhaeghen et al., 2005). The capacity of the focus of attention is discussed controversial. According to Cowan (2001), the focus of attention has a capacity of 4 ± 1 items, but in tasks of serial attention the focus of attention can hold only one single item at any given time (Garavan, 1998; McElree, 1998, 2001; Oberauer, 2002; Verhaeghen and Basak, 2005; Basak and Verhaeghen, 2011). Whereas Verhaeghen et al. (2004) claimed that extended practice expands the focus of attention up to four items, other research has shown that the focus' capacity is restricted to one and is unamenable to practice-related focus expansion (Garavan, 1998; McElree, 2001; Oberauer, 2002). Following the latter point of view, processing of a second element requires a switch operation: the required element must be retrieved into the focus of attention at the expense of the item already residing here. This process of swapping representations rapidly into and out of the focus of attention is called focus-switching (Voigt and Hagendorf, 2002). The focus-switching process can be divided into two sub-processes.

The first sub-process is defined as a switching component: items have to be switched into the focus of attention to become accessible. Representations that have been switched inside the focus of attention are in a state of privileged access and can be associated with a faster retrieval rate (as compared to representations outside the focus of attention that have to be switched into the focus of attention at first to become accessible). In accordance to McElree (2001) differences in the speed of retrieving the representation of an item (measured by response times) reflect differences in its accessibility. Differences in the speed of retrieving items into the focus of attention can thus be interpreted as differences in the efficiency of the switching component.

The second sub-process of focus-switching is a maintenance-component: information not attended at the moment (aside the current processing stream) has to be kept available outside the focus of attention until it is needed. Information that is not maintained could not be retrieved correctly into the focus of attention, in other words: it is not available for switching. Keeping an element available outside the focus of attention can be interpreted as the maintenance-component of focus-switching. Since the representations outside the focus of attention are subjected to interference and decay (Verhaeghen et al., 2005), the accuracy of retrieving them into the focus of attention can be considered as an index of an item's availability (McElree, 2001). Differences in the accuracy can thus be interpreted as differences in the efficiency of the maintenance-component of focus-switching. Recent focus-switching studies showed that switching focal attention comes at costs of both the efficiency of the switching component and the efficiency of the maintenance-component for younger and older adults (e.g., Garavan, 1998; McElree, 2001; Verhaeghen and Hoyer, 2007).

Even thought executive functioning shows age-related changes (e.g., Hamm and Hasher, 1992; Kray et al., 2005; Ryan et al., 2007), dissociations in the amount of age-related impairments have also been reported (Kray and Lindenberger, 2000; Verhaeghen et al., 2005). In processes that involve active selection or inhibition of stimuli, there seem to be no age deficits. In processes that involve the switch of attention from one aspect of a stimulus to a different aspect (or between different stimuli), age-related declines were absent as well. However, age difference can be found in processes involving the maintenance of two distinct mental task sets (Verhaeghen and Cerella, 2002). A similar differentiation pertains also to sub-processes within executive functioning. For task switching, as an example, age-related changes are not present in local switching, which can be interpreted as a marker of switching quality *per se*, but age effects are given in global switching, which can be considered as a marker of maintaining one task-set while operating on another (Kray and Lindenberger, 2000; Verhaeghen et al., 2005; Wasylyshyn et al., 2011). Most interestingly, focus-switching also shows differential age-sensitivity in its two sub-processes. There are no age differences with regard to the speed of switching once general slowing is taken into account, but there are age-related declines in the accuracy of maintaining representations (Verhaeghen and Basak, 2005; van Gerven et al., 2007, 2008; Verhaeghen and Hoyer, 2007; Dorbath and Titz, 2011). This pattern mirrors the results from task switching indicating that executive functions in older age are primarily affected with respect to the maintenance of representations.

Given that developmental researchers demonstrated substantial age-related changes in executive functioning and that cognitive abilities are important determinants of individual economic and social success (Heckman et al., 2006), it is of special interest to assess the range and magnitude of cognitive trainability and cognitive plasticity in working memory and executive control in various age ranges. Trainability of cognitive abilities can be associated with improvements in the practiced task, whereas cognitive plasticity can be defined as performance improvement that is generalizable to a larger range of non-trained tasks (Noack et al., 2009; Klingberg, 2010). Cognitive interventions provide the opportunity to study age differences in cognitive trainability and usually result in performance gains in younger and older adults (Dahlin et al., 2008; Li et al., 2008; Hertzog et al., 2009; Karbach and Kray, 2009; Lustig et al., 2009) and even in old–old adults beyond the age of 80 (Buschkuehl et al., 2008). Training studies on episodic memory showed generally smaller performance gains for older adults as compared to younger adults. This suggests that the amount of cognitive improvement is reduced in older age (e.g., Singer et al., 2003) and can be described with an amplification model (Verhaeghen and Marcoen, 1996). According to an amplification model, pretest performance is positively correlated to training gains and therefore age differences in performance are not reduced by training. In contrast, training gains for executive functions seem to follow a compensation model, according to which pretest performance is negatively correlated to training gains. In this model age differences in performance can be reduced by training (Kray and Lindenberger, 2000; Karbach and Kray, 2009). Former results indicate that the influence of cognitive training may not be reduced in older adults for the domain of executive functioning. Evidence for this assumption can be found in task switching (e.g., Dahlin et al., 2008). Task switching training shows a larger reduction of global switch costs (SC) for older adults than for younger adults. For the age-insensitive local SC, however, trainability seems not to be affected by age (e.g., Kray and Lindenberger, 2000; Karbach and Kray, 2009). Furthermore, in dual task training increases in accuracy were larger in older than in younger adults, whereas in reaction time costs younger and older adults showed equivalent reductions (Bherer et al., 2006). In conclusion, older adults seem to have larger training gains than younger adults in executive functions that show age-related sensitivity in untrained state, but not in such domains that are spared by aging. Whether a compensation model of executive control training is valid might therefore depend on whether or not age-related impairments are given in the function that is trained.

Studies dealing with training effects in focus-switching are scarce as yet and limited to younger adults. Garavan (1998) showed that training leads to performance improvements in focus-switching for younger adults. Little is known, however, about the amount of trainability or even plasticity in focus-switching in older age and whether potential training gains follow an amplification model or a compensation model. Since focus-switching is involved in almost any cognitive task requiring the processing of more than a single sequential stream of items its potential trainability is highly relevant with respect to maintaining cognitive functioning in older adults.

The present study investigates the influence of a repeated practice of a focus-switching task and the first goal was to assess the extent to which training can improve focus-switching performance in older and younger adults. Given a differential age-sensitivity in the two sub-processes of focus-switching (switching and maintaining), the trainability of these processes may also follow different trajectories and the general trainability of these two components may differ for older as compared to younger adults. Since training gains in age-sensitive processes of executive control seem to follow a compensation model (see Kray and Lindenberger, 2000; Bherer et al., 2006; Karbach and Kray, 2009), the maintenance-component of focus-switching may also follow a compensation model. In contrast, the improvement after training with regard to the age-insensitive switching component may not be influenced by participants' age, as has been shown for local task switching, for example (see above).

Because (1) age effects differ for switching and maintenance and (2) we argue that the age-related trainability of these two components may also differ, our second aim was to examine whether age-related effects in the trainability of the switching component and the maintenance-component differ depending on the kind of training. Thus, training conditions were created that differentiated between conditions in which participants mainly trained maintenance or switching. Training conditions emphasizing the maintenance-component of focus-switching concentrate on the process of representations' maintenance outside the focus of attention. In such maintenance training conditions long periods are realized in which a specific (first) item is subject to the current processing stream while a different (second) item has to be maintained outside the focus of attention until a switch to this second item occurs. The frequency of changes is low and the period of maintaining a specific item outside the focus of attention is long. Training conditions emphasizing the switching component demand the process of switching representations into and out of the focus of attention. In such switching conditions the frequency of changes (from a first item to a second item and reverse) is high, whereas the period of maintaining a specific item outside the focus of attention is short. Training gains in the maintenance-component should improve considerably, if dominantly maintenance is trained, but not when switching is mainly trained, whereas training gains in the switching component should improve when switching is primarily trained, but not maintenance.

To summarize, the main question of the present study is whether the trainability of the switching component and the maintenance-component do follow different age-related trajectories with respect to the age-related pattern of losses and stability (compensation or not), and the second question centers around the (age-related) specificity of training gains depending on the kind of training.

MATERIALS AND METHODS

In order to examine age-related differences in the trainability of focus-switching, the given study adopted a pretest–training–posttest design. All participants completed six sessions, one session for the pretest and one session for the posttest assessment, as well as four sessions of intensive training in-between.

PARTICIPANTS

Ninety-six younger adults and 96 older adults were recruited for the study. Five younger and five older adults, however, did not take part in all six sessions and another six young participants had to be excluded because of technical problems during data collection. For this reason the sample size was reduced to 85 younger adults and 91 older adults. Younger adults were university-students of the University of Frankfurt, who participated for course credit or were paid a monetary reward of €80 (∼US $ 115). Older adults were members of the University of the Third Age, which offers scientific education for adults from 50 years up, or were recruited in senior care organizations using flyers that described the study. Older adults were also paid € 80 (∼US $ 115) for participating in the six study sessions. Ethic standards were followed in the conduct of the study as approved by the Frankfurt Goethe University's Ethics Committee for Psychology. All subjects participated voluntarily and could abdicate at any time from the study without any personal disadvantages. Demographic characteristics of the sample are summarized in **Table 1**.

CONTINUOUS COUNTING TASK

The task used to assess focus-switching was a continuous counting task (adapted from Garavan, 1998; Voigt and Hagendorf, 2002). In the continuous counting task, participants have to keep track of the number of two symbols occurring successively on a computer monitor. Attentional switches must be made every time the object

Table 1 | Descriptive statistics for the participants: gender distribution, age range, and means (*SD*) for age, physical health, and vocabulary.

	Age group	
	Younger	**Older**
N	85	91
Male/female	21/64	29/62
Age range	19–35	59–80
Mean age	24.07 (3.79)	66.27 (4.75)
Physical health[A]	3.96 (0.78)	3.86 (0.83)
Vocabulary[B]	33.49 (2.52)	35.48 (2.70)

[A] *Reported on a 5-point scale (1 = bad to 5 = very good).*
[B] *The older adults scored significantly higher on the vocabulary test (Schmidt and Metzler, 1992) than the younger adults, suggesting that semantic knowledge increased during adulthood.*

changes (switch-trials). In this study participants were asked to count geometric figures (rectangles and triangles) as accurate and as fast as possible.

Each counting sequence began with a starting screen including a rectangle and a triangle. A number was presented below each object (see **Figure 1**). This numbers varied between 1 and 3 and had the function of starting values from which on subjects should start counting. Having memorized the starting count, participants initiated a counting sequence by pressing the space bar. Participants counted the geometric figures at their own pace. Whenever they pressed the space bar, the next object was displayed. An asterisk preceded each figure for 500 ms, so that participants had a visual confirmation that a new object will be presented. The intervals between the presentation of an object and the participants' following bar press were recorded as response times. At the end of each counting sequence subject had to enter their two final counts (see **Figure 1**). Here, the accuracy of the counting was recorded.

Two types of trials are possible in a given sequence: if a rectangle followed a triangle or a triangle followed a rectangle, the participants had to switch from one count to the other (switch-trial). If a rectangle followed a rectangle or a triangle followed a triangle the participants had to update the same count twice in a row (non-switch-trial).

In pretest and posttest the number of sequences was 18; in each of the four training sessions the number of sequences was 36. Thus all participants completed 144 sequences over the four training sessions plus 36 sequences in pretest and posttest. The length of the counting sequences varied between 17 and 19 geometric figures presented subsequently, so that participants could not predict the end of a current counting sequence. Additionally, the sequences differed in their number of switch- and non-switch-trials; in some sequences 25% of switch-trials were realized, in some sequences 50% of switch-trials were realized, and finally, in some sequences 75% of switches were realized (see bottom of **Figure 1**). The exact number of switch-trials per sequences in the training sessions depends on the training condition (see the next paragraph). In pretest and posttest, one-third of the sequences include 25% of switch-trials, one-third of the sequences include 50% of switch-trials, and one-third of the sequences include 75% of switch-trials. The number of triangles and rectangles were counterbalanced across sequence length and switch-trials. The presentation of the sequences varied randomly.

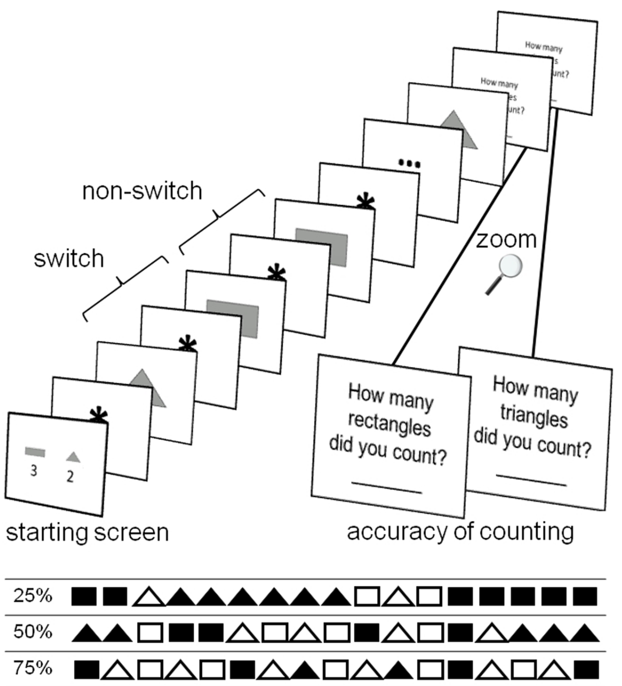

FIGURE 1 | An illustration of the continuous counting task: the top of the figure illustrates the sequence procedure in the continuous counting figures task with starting values of 3 for rectangles and 2 for triangles, an exemplary counting sequence, and the two accuracy screens. The bottom of the figure gives examples for sequences of the three frequency classes (light objects mark switch-trials).

TRAINING CONDITIONS

To assess age-related differences in the trainability of maintenance and switching, four training conditions were created based on a 2 (switching demand) × 2 (maintenance demand) factorial design. The four conditions vary according to their switching demand (high–low) and their maintenance demand (high–low).

(1) In a first condition, the frequency of switching was low. In each session half of the sequences include 25% of switch-trials and half of the sequences consisted of 50%-switch-trials (to exclude predictability of switches). Since the small number of switches places priority on maintenance, this condition was named low-switching, high-maintenance (lS–hM) condition.
(2) In a second condition, the frequency of switching was high. In this condition half of the sequences include 75%-switch-trials and half of the sequences include 50%-switch-trials (to exclude predictability of switches). Since these sequences require switching in particular, the condition was named high-switching, low-maintenance (hS–lM) condition.
(3) In a third training condition, high-switching demands as well as high-maintenance demands were realized: half of the sequences include 25%-switch-trials and half of the sequences include 75%-switch-trials. This condition was named high-switching, high-maintenance (hS–hM) condition, because in half of the sequences switching-requirements are high and in half of the sequences maintenance requirements are high.
(4) Fourthly, there was a "low–low" condition in which neither the demand to switch nor the demand to maintain was a defining feature of the task. In this condition, people simply did a choice-reaction task: participants responded as quickly as possible to a stimulus with a specific key assigned to the stimuli. In this task the same stimuli-sequences as in the continuous counting task were presented. This condition was named the low-switching, low-maintenance (lS–lM) condition.

Data were analyzed according to the impact of high vs. low-maintenance demands and according to the impact of high vs.

low-switching demands on training gains in error rates and reaction times (RTs). Therefore, two groups for each factor of the design (switching demand and maintenance demand) were aggregated from the four training conditions. With respect to the factor maintenance a high-maintenance group includes training conditions 1 (lS–hM), and 3 (hS–hM). A low-maintenance group includes the training conditions 2 (hS–lM) and 4 (lS–lM). Referring to the factor switching demand two groups differing in high- and low-switching demands were conducted. The group with high-switching demands includes the two training conditions 2 (hS–lM) and 3 (hS–hM). The group with low-switching demands includes training conditions 1 (lS–hM) and 4 (lS–lM).

MEASUREMENT OF FOCUS-SWITCHING

Because the focus-switching paradigm used in this study allows the separation of two executive sub-processes, namely the switching between two stimuli and the maintenance of stimuli outside the focus of attention, two measures of executive control are given:

(1) Switch costs: SC are defined as the difference in reaction time between switch-trials and non-switch-trials.
(2) Accuracy of the counting: only sequences with a correct final count for both, rectangles as well as triangles, were scored as correct. All sequences with a wrong final count for one or both of the objects (e.g., a wrong count for rectangle and/or for triangle) were scored as incorrect (error rates).

PROCEDURE

The focus-switching training, including pretest and posttest session as well as the four training sessions was completed within a 3-week period with usually two experimental sessions per week. In all six sessions participants were tested in small groups of two to six participants. The pretest and the posttest took 90–120 min including breaks; each of the four training sessions lasted approximately 45 min.

Participants performed the cognitive tasks on HP Compaq 615 laptop computers and responded with keys on the standard laptop keyboard and on DirectIN High Speed Button-Box v2008 (Empirisoft). The cognitive tasks were compiled in DirectRT (version 2008.1.0.13) and MediaLab (version 2008.1.33).

Subjects were encouraged to choose a comfortable viewing distance from the screen. In the pretest session participants firstly completed questions on health and demographics and a paper-and-pencil vocabulary test (WST, Schmidt and Metzler, 1992), in which real words in a row should be marked among non-sense distractor words. Subsequently participants performed the continuous counting task to assess focus-switching followed by a choice-reaction task assessing processing speed.

After the pretest session participants were assigned to one of the four training conditions based on (1) their pretest performance in the vocabulary test (WST, Schmidt and Metzler, 1992) and (2) on their processing speed in the choice-reaction task to ensure comparable baseline performances over the training groups. There are no differences in the baseline performances over the training groups in the vocabulary score and the processing speed as well as in the error rates and SC in focus-switching.

Due to the fact that training effects were defined as performance improvement at posttest relative to baseline performance at pretest, the pretest and posttest sessions were identical in the experimental tasks except that the vocabulary test was only done in the pretest session.

RESULTS

The focus of interest in the study was in the amount of training gains and not in the time course of practice effects across the four training sessions. Thus, the following analyses were limited to the comparison of participants' pretest and posttest behavior.

In a first step, accuracy data were analyzed to assess training gains in maintenance. For this purpose a 2 (Session: pretest, posttest) × 2 (Switching demand: high, low) × 2 (Maintenance demand: high, low) × 2 (Age group: younger, older) design was used to analyze error rates. In a second analysis, RTs were examined to assess training gains in the efficiency of switching. For this purpose the same analysis with the additional factor of Trial condition was conducted, but on RTs this time: 2 (Trial condition: switch, non-switch) × 2 (Session: pretest, posttest) × 2 (Switching demand: high, low) × 2 (Maintenance demand: high, low) × 2 (Age group: younger, older).

With respect to the first research question training gains should follow a compensation model for processes that show initial age-related impairments. In focus-switching, the process of maintenance is expected to show such impairments, whereas the switching component is expected to be age-invariant. Since maintenance is assessed by accuracy/error rates, in the first analysis on error rates, an interaction of session by age group was expected. Higher improvements for older compared to younger adults from pretest to posttest would indicate the adequacy of a compensation model of training for maintenance.

In the analysis of RTs (serving as a marker of switching efficiency) no triple interaction of trial condition by session by age group should occur, since a similar training improvement for the age-invariant switching component was expected as has been described in the introduction.

According to the question of the specificity of training gains depending on which component has been trained (e.g., a training of switching should reduce SC but not error rates), in the analysis of error rates an interaction of session by maintenance demand and in the analysis of RTs an interaction trial condition by session by switching demand should occur. Furthermore, the interaction of session by switching demand by maintenance demand respectively of trial condition by session by switching demand by maintenance demand should be significant in both analyses (error rates and RTs) signaling the specificity of training gains depending on which component has been trained.

ANALYSIS OF ERROR RATES (ACCURACY)

The mean error rates (%) of both age groups as a function of training condition for pretest session and posttest session are shown in **Table 2**. The results of a 2 × 2 × 2 × 2 repeated-measures analysis of variance (ANOVA) with Session (pretest, posttest) as within-subjects factor and Switching demand (high, low), Maintenance demand (high, low), and Age group (young, old) as between-subjects factors was conducted to analyze training effects

Table 2 | Mean performance and *SD* for error rate, reaction time for switches (RT switch) and non-switches (RT non-switch), and switch costs as a function of age group, training group, and session (pretest, posttest).

Group	Error rate (%)		RT(ms) switch		RT(ms) non-switch		Switch costs (ms)	
	Pretest	Posttest	Pretest	Posttest	Pretest	Posttest	Pretest	Posttest
YOUNGER ADULTS								
Overall	14.51	12.48	1651.21	754.66	1110.62	543.59	540.59	211.07
(*n* = 85)	(9.89)	(11.78)	(686.44)	(537.17)	(509.80)	(328.29)	(269.48)	(247.88)
lS–hM	11.38	7.93	1655.18	611.17	1139.94	439.43	515.24	171.74
(*n* = 21)	(8.33)	(9.39)	(521.61)	(324.07)	(350.79)	(145.49)	(323.29)	(171.46)
hS–lM	14.29	10.05	1616.45	645.89	1057.67	497.97	558.78	147.92
(*n* = 21)	(8.16)	(11.87)	(688.39)	(366.24)	(462.53)	(232.06)	(302.20)	(194.33)
hS–hM	15.91	14.14	1628.54	551.64	1059.64	435.85	568.90	115.79
(*n* = 22)	(9.89)	(13.36)	(503.69)	(233.50)	(331.62)	(135.04)	(302.85)	(118.76)
lS–lM	16.04	17.72	1705.95	1219.62	1187.67	806.28	518.28	413.34
(*n* = 21)	(12.48)	(10.34)	(980.65)	(780.48)	(791.31)	(509.58)	(284.49)	(338.44)
OLDER ADULTS								
Overall	21.18	10.13	1762.38	1105.43	1225.74	779.97	536.64	325.46
(*n* = 91)	(12.69)	(10.49)	(540.21)	(389.12)	(420.62)	(243.66)	(274.55)	(254.84)
lS–hM	19.91	5.79	1908.99	1040.34	1345.75	706.31	563.24	334.03
(*n* = 24)	(13.89)	(7.94)	(693.75)	(402.82)	(457.11)	(175.32)	(375.97)	(289.85)
hS–lM	18.75	6.02	1672.36	1012.63	1155.25	782.15	517.11	230.48
(*n* = 24)	(11.91)	(7.49)	(506.67)	(347.61)	(369.22)	(230.89)	(271.17)	(186.42)
hS–hM	22.22	8.08	1774.19	1074.55	1261.72	771.54	512.47	303.01
(*n* = 22)	(12.72)	(8.53)	(548.94)	(415.55)	(552.66)	(322.56)	(207.34)	(260.16)
lS–lM	24.34	21.96	1685.34	1318.24	1131.45	870.49	553.89	447.75
(*n* = 21)	(10.47)	(9.37)	(325.90)	(332.38)	(210.62)	(214.63)	(212.18)	(237.69)

In pretest there are no significant differences in error rates and switch costs between the four training conditions within the age groups.

in maintenance. The ANOVA results can be seen in **Table 3**. Reductions of error rates as a function of age group and training condition in terms of maintenance demand and switching demand are presented in **Figure 2**.

Training gains in maintenance

The ANOVA demonstrated a main effect of Session $F(1,168) = 55.35$, $MSE = 65.67$, $\eta^2 = 0.25$, $p < 0.001$. There was a performance improvement in accuracy in the posttest compared to the pretest. In addition, the interaction of Session by Age group was significant. Older adults were outperformed by younger adults in the pretest session ($M_{\text{older}} = 21.18\%$; $M_{\text{younger}} = 14.51\%$; $F = 15.56$, $\eta^2 = 0.08$, $p < 0.001$), supporting the idea of initial age effects in maintenance. However, older adults improved significantly to 10.13% of errors in the posttest session ($F = 81.21$, $\eta^2 = 0.33$, $p < 0.001$, Cohen's $d = 0.95$), whereas younger adults showed less improvement in the posttest session to 12.48% ($F = 2.66$, $\eta^2 = 0.02$, $p < 0.10$, Cohen's $d = 0.19$), indicating that although both age groups improved their performance older adults showed a higher pretest–posttest gain than younger adults.

Specificity of maintenance training gains

The main effect of Maintenance demand $F(1,168) = 4.90$, $MSE = 163.30$, $\eta^2 = 0.03$, $p = 0.03$ and its interaction with Session $F(1,168) = 4.98$, $MSE = 65.67$, $\eta^2 = 0.03$, $p = 0.03$ reached significance, indicating performance improvement in the high-maintenance demand training group compared to the low-maintenance demand conditions from pretest to posttest. Although both groups (high and low demand) increased performance in posttest in contrast to the pretest, the high-maintenance demand trainings lead to significant less error rates in posttest compared to the low-maintenance demand trainings ($F = 10.96$, $\eta^2 = 0.06$, $p = 0.001$).

With respect to the expectation of the trainings' specificity, the switching demand should not contribute to the maintenance training gains. Indeed, there was no significant main effect for Switching demand, but the analysis revealed a significant interaction between Session and Switching demand $F(1,168) = 4.24$, $MSE = 65.67$, $\eta^2 = 0.03$, $p = 0.04$. Improvement in the error rates was found even for high-switching demand training compared to low-switching demand training. The high-switching demand training group showed significant less error rates in posttest compared to the low-switching demand group ($F = 6.38$, $\eta^2 = 0.04$, $p = 0.01$). Furthermore, the two-way interaction Switching demand by Maintenance demand $F(1,168) = 18.28$, $MSE = 163.30$, $\eta^2 = 0.10$, $p < 0.001$ and the three-way interaction Session by Switching demand by Maintenance demand $F(1,168) = 6.44$, $MSE = 65.68$, $\eta^2 = 0.04$, $p = 0.01$ were significant, indicating that a high demand training, especially of the maintenance-component, leads to better performance improvement regarding error rates than a low

Table 3 | Analysis of variance results for the pretest and posttest data based on error rates (%) for the Maintenance demand and for the Switching demand groups.

Effect	Error rates (%)			
	df	*F*	*MSE*	η^2
Session	1,168	55.35***	65.67	0.25
Age group	1,168	3.11*	163.30	0.02
Switching demand	1,168	2.14	163.30	0.01
Maintenance demand	1,168	4.90**	163.30	0.03
Session × age group	1,168	25.95***	65.67	0.13
Session × switching demand	1,168	4.24**	65.67	0.03
Session × maintenance demand	1,168	4.98**	65.67	0.03
Age group × switching demand	1,168	2.68	163.30	0.02
Age group × maintenance demand	1,168	0.30	163.30	0.00
Switching demand × maintenance demand	1,168	18.28***	163.30	0.10
Session × age group × switching demand	1,168	0.88	65.67	0.01
Session × age group × maintenance demand	1,168	2.46	65.67	0.01
Session × switching demand × maintenance demand	1,168	6.44**	65.67	0.04
Age group × switching demand × maintenance demand	1,168	0.26	163.30	0.00
Session × age group × switching demand × maintenance demand	1,168	13.19	65.67	0.00

****p < 0.01; **p < 0.05; *p < 0.10.*

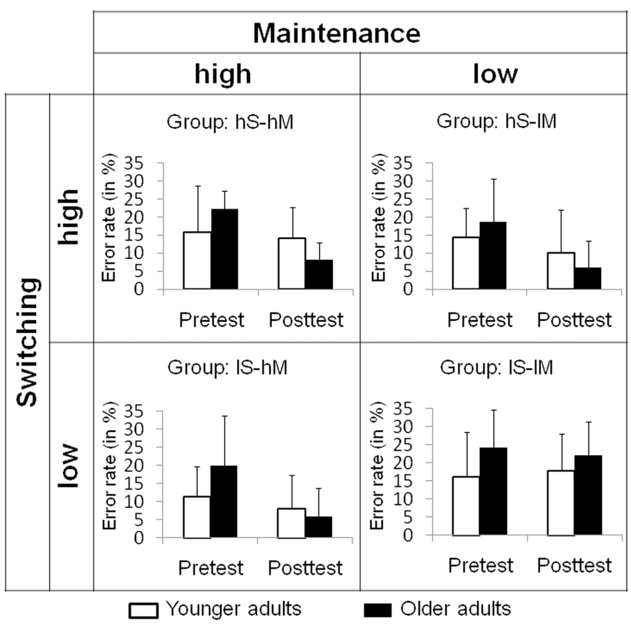

FIGURE 2 | Error rates (%) as a function of session, age group, and training group.

demand training of both components. There were no significant interactions with Age group and neither the other three-way interactions nor the four-way interaction showed significance.

Analyses of the simple effects revealed significant improvements from pretest to posttest in the three training conditions with high demand in one or in both focus-switching components (lS–hM: $F = 26.95$, $\eta^2 = 0.14$, $p < 0.001$, Cohen's $d = 0.86$; hS–lM: $F = 24.54$, $\eta^2 = 0.13$, $p < 0.001$, Cohen's $d = 0.69$; hS–hM: $F = 21.20$, $\eta^2 = 0.11$, $p < 0.001$, Cohen's $d = 0.65$).

ANALYSIS OF REACTION TIME

Reaction times above 2 SD from the individual's mean and RTs less than 200 ms were removed from the data set as outliers. Generally, only RTs corresponding to correct trials were analyzed. A logarithmic transformation was applied to the data to correct for age-related general slowing and to control for age-related differences in baseline performance. Consequently, age by condition interactions can be seen as relatively independent of age differences in baseline performance (Cerella, 1994; Meiran, 1996).

The mean RTs in ms and the SC of both age groups for pretest session and posttest session are shown in **Table 2**. As mentioned above in further analyses log-transformed RTs were used. A 2 × 2 × 2 × 2 × 2 ANOVA with Trial Condition (switch, non-switch) and Session (pretest, posttest) as within-subjects factors, and Switching demand (high, low), Maintenance demand (high, low), and Age group (younger, older) as between-subjects factors was conducted to analyze training effects in switching. The results can be depicted from **Table 4**. Reductions of SC as a function of age group and training condition in terms of maintenance demand, and switching demand are presented in **Figure 3**.

Training gains in switching (reduction of switch costs)

A significant main effect for Trial condition $F(1,168) = 954.26$, $MSE = 0.01$, $\eta^2 = 0.85$, $p < 0.001$ indicates faster RTs in non-switch-trials than in switch-trials (SC). There were also significant main effects of Session $F(1,168) = 798.12$, $MSE = 0.02$, $\eta^2 = 0.83$, $p < 0.001$ and of Age group $F(1,168) = 37.57$, $MSE = 0.07$, $\eta^2 = 0.18$, $p < 0.001$. Both age groups got faster from pretest to posttest. The significant interaction of Session by Trial condition indicates that SC were reduced by training $F(1,168) = 34.56$, $MSE = 0.00$, $\eta^2 = 0.17$, $p < 0.001$. Furthermore, the interaction of Session by Age group $F(1,168) = 66.14$, $MSE = 0.02$, $\eta^2 = 0.28$, $p < 0.001$ as well as the interaction of Session × Age group × Trial condition $F(1,168) = 12.23$, $MSE = 0.00$, $\eta^2 = 0.07$, $p < 0.001$ reached significance. Even though there were no age differences in the pretest session (SC in pretest: $SC_{older} = 533.51$ ms; $SC_{younger} = 539.59$ ms), both age groups improved significantly in the pretest–posttest comparison (younger: $F = 108.83$, $\eta^2 = 0.39$, $p < 0.001$, Cohen's $d = 1.55$; older: $F = 47.84$, $\eta^2 = 0.22$, $p < 0.001$, Cohen's $d = 0.80$). Of utmost importance was that younger adults showed better training gains than older adults (SC in posttest $SC_{younger} = 215.04$; $SC_{older} = 326.85$ ms, $F = 4.43$, $p = 0.04$, $\eta^2 = 0.03$).

Specificity of switching training gains

The main effect for Switching demand $F(1,168) = 5.15$, $MSE = 0.07$, $\eta^2 = 0.03$, $p = 0.02$ revealed to be significant as well

Table 4 | Analysis of variance results for the pretest and posttest data based on log RTs for the Maintenance demand and for the Switching demand groups.

Effect	Log RT			
	df	*F*	*MSE*	η^2
Session	1,168	798.12***	0.02	0.83
Trial condition	1,168	954.26***	0.01	0.85
Age group	1,168	37.57***	0.07	0.18
Switching demand	1,168	5.15**	0.07	0.03
Maintenance demand	1,168	3.10*	0.07	0.02
Session × age group	1,168	66.14***	0.02	0.28
Session × switching demand	1,168	10.90**	0.02	0.06
Session × maintenance demand	1,168	42.83***	0.02	0.20
Session × trial Condition	1,168	34.56***	0.00	0.17
Trial condition × age group	1,168	0.53	0.01	0.00
Trial condition × switching demand	1,168	3.55*	0.01	0.02
Trial condition × maintenance demand	1,168	0.76	0.01	0.00
Age group × switching demand	1,168	0.96	0.07	0.01
Age group × maintenance demand	1,168	1.86	0.07	0.01
Switching demand × maintenance demand	1,168	3.21*	0.07	0.02
Session × age group × switching demand	1,168	4.49**	0.02	0.03
Session × age group × maintenance demand	1,168	3.63*	0.02	0.02
Session × switching demand × maintenance demand	1,168	19.40***	0.02	0.10
Session × trial condition × age group	1,168	12.23**	0.00	0.07
Session × trial condition × switching demand	1,168	18.98***	0.00	0.10
Session × trial condition × maintenance demand	1,168	0.29	0.00	0.00
Trial condition × age group × switching demand	1,168	0.11	0.01	0.00
Trial condition × age group × maintenance demand	1,168	0.40	0.01	0.00
Trial condition × switching demand × maintenance demand	1,168	3.89*	0.01	0.02
Age group × switching demand × maintenance demand	1,168	0.58	0.07	0.00
Session × age group × switching demand × maintenance demand	1,168	1.35	0.02	0.01
Session × trial condition × age group × switching demand	1,168	1.44	0.00	0.01
Session × trial condition × age group × maintenance demand	1,168	2.79*	0.00	0.01
Session × trial condition × switching demand × maintenance demand	1,168	3.81*	0.00	0.02
Trial condition × age group × switching demand × maintenance demand	1,168	0.001	0.01	0.00
Session × trial condition × age group × switching demand × maintenance demand	1,168	0.03	0.00	0.00

****p < 0.01; **p < 0.05; *p < 0.10.*

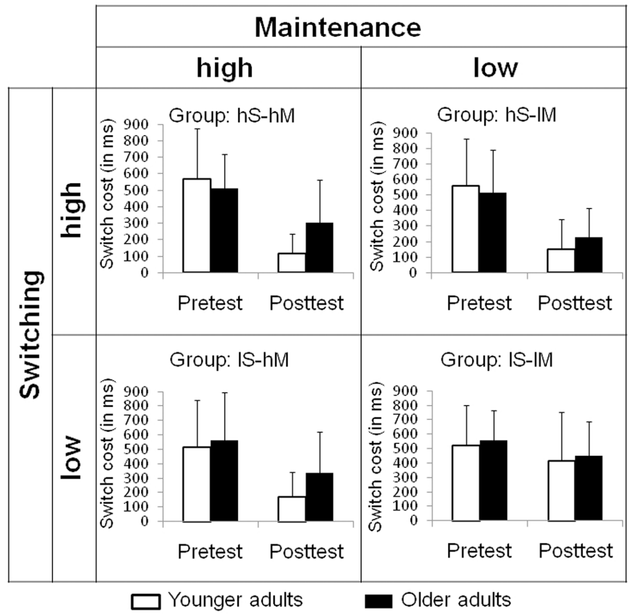

FIGURE 3 | Switch costs (ms) as a function of session, age group, and training group.

as the Switching demand by Session interaction $F(1,168) = 10.90$, $MSE = 0.02$, $\eta^2 = 0.06$, $p = 0.001$ and the three-way interaction Trial condition by Session by Switching demand $F(1,168) = 18.98$, $MSE = 0.00$, $\eta^2 = 0.10$, $p < 0.001$. High demand training in the switching component resulted in better performance improvement in posttest than training with low demand in this component ($F = 10.39$, $\eta^2 = 0.06$, $p = 0.002$). Additionally, Session interacted with Maintenance demand $F(1,168) = 42.83$, $MSE = 0.02$, $\eta^2 = 0.20$, $p < 0.001$ indicating that even training in high-maintenance demand compared to low-maintenance demand increased training gains in RTs. However, the interaction of Trial condition by Session by Maintenance was not significant.

As for the data on accuracy, analyses of the simple effects revealed a significant improvement from pretest to posttest in the three training conditions with high demands in one or both focus-switching components (lS–hM: $F = 329.03$, $\eta^2 = 0.66$, $p < 0.001$, Cohen's $d = 0.91$; hS–lM: $F = 220.86$, $\eta^2 = 0.57$, $p < 0.001$, Cohen's $d = 1.34$; hS–hM: $F = 284.63$, $\eta^2 = 0.63$, $p < 0.001$, Cohen's $d = 1.44$).

The four-way interaction involving Trial condition, Session, Switching demand, and Maintenance demand $F(1,168) = 3.81$, $MSE = 0.00$, $\eta^2 = 0.02$, $p = 0.05$ indicates that performance improvement emerged through training especially in the high-switching demand conditions and even in the high-maintenance demand conditions (hS–lM; hS–hM; lS–hM; $p < 0.001$), but there was marginal improvement in training with low demand of both components.

Furthermore, the Session by Age group by Switching demand interaction $F(1,168) = 4.49$, $MSE = 0.02$, $\eta^2 = 0.03$, $p = 0.04$, as well as the Session by Age group by Maintenance demand interaction $F(1,168) = 3.63$, $MSE = 0.02$, $\eta^2 = 0.02$, $p = 0.06$ were at least marginally significant ($p < 0.10$). In addition the four-way interaction Trial condition by Session by Age group by Maintenance demand $F(1,168) = 2.79$, $MSE = 0.00$, $\eta^2 = 0.01$, $p = 0.09$ reached marginally significance ($p < 0.10$). These findings indicate that younger adults benefited more from training in all high demand (hS–lM; hS–hM; lS–hM; $p < 0.001$) groups compared to older adults.

DISCUSSION

The aim of the given study was to explore the age-related trainability of the two components of focus-switching, maintenance, and switching. Given the differential age-sensitivity of these processes, we used a training approach to study potential age-related differences. For training gains in the age-sensitive process of maintaining representations outside the focus of attention a compensation model was postulated in the sense of larger training gains for older adults. In contrast, the trainability of the age-insensitive process of switching representations into and out of the focus of attention should not be influenced by age group. Furthermore, the study considered the question of how the specific type of training contributes to performance improvements. To this end, older and younger participants were examined by means of a pretest–training–posttest design and were trained in focus-switching using a continuous counting task. The improvement from pretest to posttest was assessed. In four sessions of intensive practice between pretest and posttest, participants were assigned to one of four training conditions varying in the demand of maintenance and switching.

TRAINABILITY OF FOCUS-SWITCHING IN YOUNGER AND OLDER ADULTS

Analysis of the pretest and posttest data revealed reduced error rates, as well as reduced SC for both age groups after practice in one or both of the focus-switching components (high demand training conditions). In contrast, training with low demands in the sub-processes did not lead to benefits in the focus-switching task. The finding that younger adults were able to improve their focus-switching performance as a function of training is consistent with previous results (Garavan, 1998). More important, the present study showed that even older adults can improve their performance in both, accuracy and SC. This finding mirrors results of other cognitive intervention studies in older age (e.g., Willis and Nesselroade, 1990; Bherer et al., 2006; Brehmer et al., 2007; Dahlin et al., 2008; Karbach and Kray, 2009). Therefore the influence of training regarding cognitive capabilities and specifically regarding the focus-switching process seems to be considerable even in older adults. Despite general performance improvements, age differences according to the two domains of maintenance and switching became obvious.

Regarding accuracy of counting, pretest data showed a disproportionate decrease for older adults compared to younger adults (see also Dorbath and Titz, 2011) signaling problems in the maintenance of representations outside the focus of attention. After training sessions, however, older adults performed equally well or even slightly better than younger adults. Similar improvements have been reported for the maintenance domain in other executive control training approaches. Task switching training, for example, shows a larger reduction of global switch cost in older adults, measuring the ability to maintain different task sets (e.g., Kray and Lindenberger, 2000). Dual task training resulted in a larger reduction of error rates in older age, as well (Bherer et al., 2006). Thus, in the maintaining domain of focus-switching poorer pretest performance is associated with larger training gains and focus-switching training reduces age differences in performance, respectively. Therefore training gains in accuracy seem to follow a compensation model of training pointing to considerable improvement in this domain even in older age.

However, in the second sub-process of focus-switching, the process of switching, no age-related differences were found in pretest data (see also Dorbath and Titz, 2011). In contrast to the accuracy domain, training resulted in smaller performance gains for older adults as compared to younger participants. This finding does not support previous findings in the switching domain of executive control trainings, which observed no age differences in trainability (e.g., Bherer et al., 2006). For this reason our hypothesis that the improvement after training with regard to the age-insensitive switching component may not be influenced by participants' age, as has been shown for local task switching (see Introduction), was not corroborated. The fact that age differences could not be reduced by training seems to be compatible with the idea of an amplification model (Verhaeghen and Marcoen, 1996), primarily found for mnemonic skills, e.g., episodic memory (Baltes and Kliegl, 1992; Brehmer et al., 2008). However, in contrast to the amplification model, older adults were not disadvantaged with regard to initial performance at pretest, but there is an age-related dissociation in the trainability of the switching process, that is, an advantage for younger as compared to older adults at posttest. Since no age-sensitivity was found in pretest, the distinct training improvements for younger and older adults cannot be seen as an amplification of superior initial performance that has been found in the pretest. The reduced training benefits of older adults, however, indicate limits of cognitive trainability in the switching domain for older adults in comparison to younger adults.

A possible explanation for this somehow surprising result – that even though no age-sensitivity was found at the performance level of switching, age-related differences in trainability were observed – may be the varying use of resources in the different age groups. According to the working memory resources assumption provided by Anderson et al. (1996), the availability of resources influences the activation level of representations inside the focus of attention (and memory elements to be processed in general). Relating to this, it can be supposed that – as a result of training – not all available resources must be used for an executive control process. If less resources can be (or are) used for the activation level inside the focus of attention, there is a lower activation difference between elements inside and out of the focus of attention and therefore less SC are given for swapping a new element inside the focus of attention. Younger adults may profit from the training in a way that they need less resources for the activation of representations inside the focus of attention. For older adults, however, first developmental losses may become obvious. After four training sessions older adults still need more resources for activating the representations inside the focus of attention. Therefore the activation difference after training is still higher for older adults, which results in higher SC. Following this line of reasoning, older adults could possibly reduce their SC to the level of the younger adults by more training sessions.

An alternative explanation for larger training gains of younger adults in switching after training might be derived from research on the extensibility of the focus of attention. Verhaeghen et al. (2004) claimed that the focus of attention is extendable by practice. Therefore, it could be supposed that whereas younger adults extend their focus of attention over the four training sessions, older adults' focus of attention is still capacity-limited to one item. An extended focus of attention consequently causes less SC. However, this idea does not fit with the accuracy results. Participants with an extended focus of attention should produce only few errors, since representations have not to be maintained outside, and are thus not subjected to interference and decay. A further idea is the development of an indistinct border between the focus of attention and the outer store instead of an extension of the focus of attention for younger adults. This is in accordance with the first assumption of a lower activation difference. If the focus of attention and the outer store become indistinct, both areas and not only the outer store (Verhaeghen et al., 2007) might be subject to interference and decay. The task used in this study cannot assess in which period of task performance an error occurs. Therefore it is possible that younger adults' errors were an effect of the indistinct border.

Finally, a third explanation of the age-sensitive trainability in switching seems to be obvious. Interestingly, older adults showed a substantial increase in accuracy as a function of training, but a smaller improvement in switching in comparison to younger adults. The younger adults showed a reverse trend: they improved more in switching as compared to the older adults, but had only a small enhancement in accuracy, reaching the same level as the older participants. Aside from different potential in cognitive trainability, this result could even be caused by different response tendencies. Referring to a speed–accuracy trade-off, older adults, realizing their initial problem in maintaining items, might have used a more conservative strategy of response (De Jong, 2001), especially in switch-trials. In that case older adults concentrated on the accuracy-component and accepted longer RTs to achieve correct answers. Young adults, on the other hand, may have concentrated on the speed component during training, which might result in low accuracy. Such different response tendencies cannot totally be excluded, although all participants were instructed to work as accurate and as fast as possible. One way to rule out a speed–accuracy trade-off is to analyze whether accuracy and speed are negatively correlated; this was however, not the case. Therefore, the age differences in the trainability of the two focus-switching sub-processes seem to be rather caused by different ability and cognitive improvement of the two age groups.

Certainly it is debatable whether it is necessary to discuss the improvement by training of a process that is not affected by age, as given for the switching component. On the other side, it might be that an upcoming age-related decline is signalized by a reduced trainability in the associated process (Bäckman, 1992; Baltes et al., 1995). In order to consider the age-related development in the switching process and even the induced trainability in the maintenance process, further research is necessary using an old–old sample. It is possible, that in an old–old sample age-related sensitivity occurs not only in maintenance, but also in switching which may then be associated with a compensation model of training gains.

TRAINABILITY AS A FUNCTION OF TRAINING DEMAND

According to the question whether the type of training has a differential influence on performance gains, highest improvement in the maintenance domain was expected for training with demand on maintenance. Highest improvement in the switching process was expected for a training that had high-switching demands. In the accuracy domain results revealed distinct training effects for participants trained with high vs. low demand in the maintenance process. However, training with high demand in the switching process either resulted in good training improvement in the accuracy domain. Data suggest that, as hypothesized, the training of the maintenance-component is a useful approach for an improvement of maintaining representations in the focus-switching process. At the same time a training of the switching component improved the process of maintaining items outside the focus of attention, in addition. Compared to the older adults, who showed clear training gains, younger adults' training improvement was relatively small. This might be caused by the high baseline performance of the younger adults.

In the switching domain similar results emerged. Training conditions including high vs. low-switching demands resulted in distinct improvements in SC. However, for the process of switching items in and out of the focus of attention, training that included high-maintenance demands also led to explicit reduction of SC.

Despite of some tendencies, there is no definite difference with respect to training gains of a training mainly requesting maintenance and a training mainly requesting switching. Due to the nature of the continuous counting task, partly both of the focus-switching sub-processes may have been trained in each specific training condition. The fact that the impact of the training seems to be rather unspecific could be caused by a task-based confounding, that is, sequences were used that included different amounts of switch-trials to reduce predictability. Concerning the focus-switching training sessions, the filling up of the "high demand switching–low-demand maintenance" and the "low-demand switch–high demand maintenance" group with each 50%-switch sequences might have been critical. Although this procedure reduced predictability, it may determine a fuzziness of the results of the different groups.

The condition in which none of the both focus-switching process has been trained showed neither improvement in the process of maintaining representation outside the focus of attention, nor in the process of switching representations into and out of the focus of attention. Therefore, it is reasonable to conclude that improvements are caused by the training of focus-switching components instead of familiarity with stimuli or task.

SHORT-COMINGS AND PROSPECTIVE RESEARCH

Although the present study has provided new findings with respect to the trainability of executive control processes in older age, there are some short-comings beside the ones already mentioned. These short-comings should be kept in mind when the results are interpreted. Even though there were clear differences in the trainability of the focus-switching processes maintenance and switching, this finding has to be interpreted cautiously. However, as revealed by the data, focus-switching training (high demand groups) nearly led to bottom effects, especially for younger adults, but even for error rates in older adults. The continuous counting task might thus have been not difficult or challenging enough. This bottom effect may have masked potential further improvements from pretest to posttest. On the one hand, young adults presumably could improve much more in SC in a more challenging task. On the other hand and more important, a more difficult task might cause different training gains in error rates. If younger adults had a lower pretest performance in accuracy than in the given study, the pattern of improvements may look different. Possibly, younger adults could reach improvements comparable to or even better than those of older adults in accuracy disproving a compensation model of training. Additionally, the fact that high- and low-demand-groups were between-subjects factors can be seen as a limitation of the present study. Differences between the groups might have been caused by general group differences rather than being attributable to the type of training. The latter assumption seems, however, unlikely, because the conditions were matched prior to the training.

Another issue concerns the better performance of the participants with high demand focus-switching training in one or both components. Even thought filler-trials (including 50% of switches) were included that served to minimize predictability of switching and maintenance demands, we cannot exclude that improvements in the posttest were due to learned expectations about the task, rather than to improvements in underlying executive processes.

With respect to actual changes in underlying cognitive processes (in the sense of plasticity), Klingberg (2010) points out that it is essential to apply a sufficient amount of training and that conditions were avoided which allow the development of task specific strategies. In the given study, the development of task specific strategies in the high demand focus-switching trainings cannot completely be excluded. Participants were, however, asked how they completed the task. Most participants (regardless of their specific condition) consequently used the classical strategy already described by Garavan (1998) combining updating and rehearsal of the counts. Nonetheless, further research on strategy use in the continuous counting task and its contribution to training gains is necessary, the more so since a self-paced task as in the given study could foster the production of specific strategies. The same is true for the amount of training necessary to reveal differences in the degree of training gains across age groups. The given study is modeled upon task switching studies in which already four training sessions led to compensatory effects in a sample of older adults. Possibly, a larger amount of training sessions could smooth the "amplification-like" pattern for switching, that is, older adults may benefit in a similar way than younger adults, if more training sessions were applied.

Since studies dealing with training effects in executive functioning and especially in focus-switching are as yet scarce, this study does only provide a first step investigating the trainability of focus-switching. Further research has to be done with respect to varying task difficulty and the number of training sessions. Especially for older adults, more than four training sessions may result in a pronounced improvement even in the switching of representations. Additionally, further research is also needed with regard to long-term effects of the focus-switching training. Recent studies show that training improvements in executive functioning can be long lasting (Dahlin et al., 2008), but long-term effects of focus-switching training have not been investigated yet. Beside long-term training gains, transfer effects to new tasks and new situations are important for the application of training programs. Therefore it is also necessary to investigate whether focus-switching training reduces age differences not only in the trained task, but also in structurally similar and dissimilar tasks. Furthermore, empirical evidence of transfer of training would support the idea of cognitive plasticity in focus-switching. Accompanied by the issues of long-term effects and transfer effects of focus-switching training, careful considerations need to be done for a focus-switching training that will be suitable in everyday life.

CONCLUSION

Taken together, the study showed substantial influence of training in each of the two focus-switching sub-processes (1) maintaining representations outside the focus of attention and (2) switching representations in and out of the focus of attention for older and younger adults. The training gains in the maintenance domain seem to follow a compensation model independent of the kind of training pointing to considerable improvements even in older age. For the switching domain the improvement seems to be reduced for older adults as compared to younger adults.

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REFERENCES

Anderson, J. R., Reder, L. M., and Llebiere, C. (1996). Working memory: activation limitations on retrieval. *Cogn. Psychol.* 221–256.

Bäckman, L. (1992). Memory training and memory improvement in Alzheimer's disease: rules and exceptions. *Acta Neurol. Scand.* 139, 84–89.

Baltes, M. M., Kühl, K.-P., Gutzmann, H., and Sowarka, D. (1995). Potential of cognitive plasticity as a diagnostic instrument: a cross-validation and extension. *Psychol. Aging* 10, 167–172.

Baltes, P. B., and Kliegl, R. (1992). Further testing the limits of cognitive plasticity in old age: negative age differences in a mnemonic skill are robust. *Dev. Psychol.* 28, 121–125.

Basak, C., and Verhaeghen, P. (2011). Three layers of working memory: focus-switch costs and retrieval dynamics as revealed by the N-count task. *Cogn. Psychol.* 23, 204–219.

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. (2006). Testing the limits of cognitive plasticity in older adults: application to attentional control. *Acta Psychol.* 123, 261–278.

Brehmer, Y., Li, S.-C., Müller, V., Von Oertzen, T., and Lindenberger, U. (2007). Memory plasticity across the life span: uncovering children's latent potential. *Dev. Psychol.* 43, 465–478.

Brehmer, Y., Li, S.-C., Straube, B., Stoll, G., Von Oertzen, T., Müller, V., and Lindenberger, U. (2008). Comparing memory skill maintenance across the lifespan: preservation in adults, increases in children. *Psychol. Aging* 23, 227–238.

Buschkuehl, M., Jaeggi, S. M., Hutchison, S., Perrig-Chiello, P., Däpp, C., Müller, M., Breil, F., Hoppeler, H., and Perrig, W. J. (2008). Impact of working memory training on memory performance in old-old adults. *Psychol. Aging* 23, 743–753.

Cerella, J. (1994). Generalized slowing in Brinley plots. *J. Gerontol.* 49, 65–71.

Cowan, N. (1997). *Attention and Memory: An Integrated Framework.* Oxford: Oxford University Press.

Cowan, N. (2001). The magical number 4 in short-term memory: a reconsideration of mental storage capacity. *Behav. Brain Sci.* 24, 87–185.

Craik, F. I. M., and Salthouse, T. A. (2008). *The Handbook of Aging and Cognition,* 3rd Edn. New York, NY: Psychology Press.

Dahlin, E., Nyberg, L., Bäckman, L., and Neely, A. S. (2008). Plasticity of executive functioning in young and older adults: immediate training gains, transfer, and long-term maintenance. *Psychol. Aging* 23, 720–730.

De Jong, R. (2001). Adult age differences in goal activation and goal maintenance. *Cogn. Psychol.* 13, 71–89.

Dorbath, L., and Titz, C. (2011). Dissociable age effects in focus-switching: out of sight, out of mind. *GeroPsych* 24, 103–109.

Fisk, J. E., and Sharp, C. A. (2004). Age-related impairment in executive functioning: updating, inhibition, shifting, and access. *J. Clin. Exp. Neuropsychol.* 26, 874–890.

Garavan, H. (1998). Serial attention within working memory. *Mem. Cognit.* 26, 263–276.

Greenwood, P. M. (2007). Functional plasticity in cognitive aging: review and hypothesis. *Neuropsychology* 21, 657–673.

Hamm, V. P., and Hasher, L. (1992). Age and the availability of inferences. *Psychol. Aging* 7, 56–64.

Hasher, L., and Zacks, R. T. (1988). “Working memory, comprehension, and aging: a review and new review,” in *The Psychology of Learning and Motivation*, ed. G. H. Bower (New York: Academic Press), 193–225.

Heckman, J. J., Stixrud, J., and Urzua, S. (2006). The effects of cognitive and noncognitive abilities on labor market outcomes and social behavior. *J. Labor Econ.* 24, 411–482.

Hertzog, C., Kramer, A. F., Wilson, R. S., and Lindenberger, U. (2009). Enrichment effects on adult cognitive development: can the functional capacity of older adults be preserved and enhanced? *Psychol. Sci. Public Interest* 9, 1–65.

Hoyer, W. J., and Verhaeghen, P. (2006). “Memory aging,” in *Handbook of the Psychology of Aging,* 6th Edn, eds J. E. Birren and K. W. Schaire (Amsterdam: Elsevier), 209–232.

Huizinga, M., Dolan, C. V., and Van Der Molen, M. W. (2006). Age-related change in executive function: developmental trends and a latent variable analysis. *Neuropsychologia* 44, 2017–2036.

Karbach, J., and Kray, J. (2009). How useful is executive control training? Age differences in near and far transfer of task-switching training. *Dev. Sci.* 12, 978–990.

Klingberg, T. (2010). Training and plasticity of working memory. *Cogn. Sci.* 14, 317–324.

Kramer, A. F., and Willis, S. L. (2002). Enhancing the cognitive vitality of older adults. *Curr. Dir. Psychol. Sci.* 11, 173–177.

Kramer, A. F., and Willis, S. L. (2003). “Cognitive plasticity and aging,” in *The Psychology of Learning and Motivation: Advances in Research and Theory*, Vol. 43, ed. B. H. Ross (New York, NY: Elsevier Science), 267–302.

Kray, J., Eppinger, B., and Mecklinger, A. (2005). Age differences in attentional control: an event-related potential approach. *Psychophysiology* 42, 407–416.

Kray, J., and Lindenberger, U. (2000). Adult age differences in task switching. *Psychol. Aging* 15, 126–147.

Li, S.-C., Schmiedek, F., Huxhold, O., Röcke, C., Smith, J., and Lindenberger, U. (2008). Working memory plasticity in old age: practice gain, transfer, and maintenance. *Psychol. Aging* 23, 731–742.

Lustig, C., Shah, P., Seidler, R., and Reuter-Lorenz, P. A. (2009). Aging, training, and the brain: a review and future directions. *Neuropsychol. Rev.* 19, 504–522.

Mayr, U., and Kliegl, R. (1993). Sequential and coordinative complexity: age-based processing limitations in figural transformations. *J. Exp. Psychol. Learn. Mem. Cogn.* 19, 1297–1320.

Mayr, U., Spieler, D. H., and Kliegl, R. (2001). *Ageing and Executive Control.* New York: Routledge.

McElree, B. (1998). Attended and nonattended states in working memory: accessing categorized structures. *J. Mem. Lang.* 38, 225–252.

McElree, B. (2001). Working memory and focal attention. *J. Exp. Psychol. Learn. Mem. Cogn.* 27, 817–835.

Meiran, N. (1996). Reconfiguration of processing mode prior to task performance. *J. Exp. Psychol. Learn. Mem. Cogn.* 22, 1423–1442.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., and Wager, T. (2000). The unity and diversity of executive functions and their contributions to complex ‘frontal lobe’ tasks: a latent variable analysis. *Cogn. Psychol.* 41, 49–100.

Noack, H., Lövdén, M., Schmiedek, F., and Lindenberger, U. (2009). Cognitive plasticity in adulthood and old age: gauging the generality of cognitive intervention effects. *Restor. Neurol. Neurosci.* 27, 435–453.

Oberauer, K. (2002). Access to information in working memory: exploring the focus of attention. *J. Exp. Psychol. Learn. Mem. Cogn.* 28, 411–421.

Ryan, J. D., Leung, G., Turk-Browne, N. B., and Hasher, L. (2007). Assessment of age-related changes in inhibition and binding using eye movement monitoring. *Psychol. Aging* 22, 239–250.

Schmidt, K.-H., and Metzler, P. (1992). *Wortschatztest (WST) [Vocabulary test].* Weinheim: Beltz Test GmbH.

Singer, T., Lindenberger, U., and Baltes, P. B. (2003). Plasticity of memory for new learning in very old age: a story of major loss? *Psychol. Aging* 18, 306–317.

van Gerven, P. W. M., Meijer, W. A., and Jolles, J. (2007). Education does not protect against age-related decline of switching focal attention in working memory. *Brain Cogn.* 64, 158–163.

van Gerven, P. W. M., Meijer, W. A., Prickaerts, J. H. M., and Van Der Veen, F. M. (2008). Aging and focus switching in working memory: excluding the potential role of memory load. *Exp. Aging Res.* 34, 367–378.

Verhaeghen, P., and Basak, C. (2005). Ageing and switching of the focus of attention in working memory: results from a modified N -Back task. *Q. J. Exp. Psychol. A* 58, 134–154.

Verhaeghen, P., and Cerella, J. (2002). Aging, executive control, and attention: a review of meta-analyses. *Neurosci. Biobehav. Rev.* 26, 849–857.

Verhaeghen, P., Cerella, J., and Basak, C. (2004). A working memory workout: how to expand the focus of serial attention from one to four items in 10 hours or less. *J. Exp. Psychol. Learn. Mem. Cogn.* 30, 1322–1337.

Verhaeghen, P., Cerella, J., Basak, C., Bopp, K. L., Zhang, Y., and Hoyer, W. J. (2007). “The ins and outs of working memory: dynamic processes associated with focus switching and search,” in *Working Memory: Behavioral and Neural Correlates*, eds N. Osaka and R. Logie (Oxford: Oxford University Press), 81–98.

Verhaeghen, P., Cerella, J., Bopp, K. L., and Basak, C. (2005). “Aging and varieties of cognitive control: a review of meta-analyses on resistance to interference, coordination and task switching, and an experimental exploration of age-sensitivity in the newly identified process of focus switching,” in *Cognitive Limitations in Aging and Psychopathology*, eds R. W. Engle, G. Sedek, U. Hecker, and D. N. Mcintosh (Cambridge: Cambridge University Press), 160–189.

Verhaeghen, P., and Hoyer, W. J. (2007). Aging, focus switching, and task switching in a continuous calculation task: evidence toward a new working memory control process. *Neuropsychol. Dev. Cogn. B Aging Neuropsychol. Cogn.* 14, 22–39.

Verhaeghen, P., and Marcoen, A. (1996). On the mechanisms of plasticity in young and older adults after instruction in the method of loci: evidence for an amplification model. *Psychol. Aging* 11, 164–178.

Voigt, S., and Hagendorf, H. (2002). The role of task context for component processes in focus switching. *Psychol. Beiträge* 44, 248–274.

Wasylyshyn, C., Verhaeghen, P., and Sliwinski, M. J. (2011). Aging and task switching: a meta-analysis. *Psychol. Aging* 26, 15–20.

Willis, S. L., and Nesselroade, C. S. (1990). Long-term effects of fluid ability training in old-old age. *Dev. Psychol.* 26, 905–910.

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