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Effects of associative learning on age differences in task-set switching

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Abstract

Costs of switching between tasks may disappear when subjects are able to learn associations between tasks, stimuli, and responses (cf. Rogers, R. D., & Monsell, S. (1995). Costs of a predictable switch between simple cognitive tasks. *Journal of Experimental Psychology: General, 124*, 207–231). The first aim of this study was to examine this possibility by manipulating stimulus-set size. We expected that costs of switching between tasks would be strongly reduced under conditions of small stimulus-set sizes ($n = 4$) as compared to large stimulus-set sizes ($n = 96$) with increasing time on task. The second aim was to determine whether younger as well as older adults were able to create associations between task components. As age differences in task switching are often found to be larger when response mappings are incompatible we also investigated interactions with response compatibility. Results of our study indicated that practice effects on switch costs were much more pronounced for small than large stimulus-set sizes, consistent with the view that the strength of associations between task components facilitates task switching. Furthermore, we found that practice benefits on task switching for small stimulus-set sizes were sensitive to age and response compatibility. In contrast to younger adults, who showed a reduction of switch costs for both response mapping conditions, older adults showed a reduction of switch costs only when response mappings were compatible. That is, older adults showed less associative learning when the currently irrelevant task feature had to be suppressed, supporting the view that older adults have primarily problems in separating overlapping task-set representations.

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1. Introduction

Research on switching between mental task sets examines the flexibility of the cognitive system to adapt to internal goal settings according to environmental changes. Adopting a mental task set can be defined as an intention to perform a particular task that is relatively independent of a specific stimulus that will occur (cf. Rogers & Monsell, 1995). Most experiments use very simple tasks to induce a task set, for instance, subjects are told to press a left key if a red light appears, and to press the right key if a green light appears. To employ such a task set, participants need to coordinate sensory, cognitive, and motor processes such as encoding the stimulus attributes, selecting the appropriate response, and planning and executing the correct motor response. Usually the configuration of a task set is relatively fast and subjects need only a few trials to perform new task instructions without errors. In recent years a couple of researchers have investigated processes associated with the efficiency to reconfigure the cognitive system from one task-set instruction to a new one. The efficiency to reconfigure task sets is indexed by switch costs that are determined as the difference between the performance on trials in which the task set is changed and on trials in which the same task set is repeated (e.g., Allport, Styles, & Hsieh, 1994; Meiran, 1996; Rogers & Monsell, 1995; Rubinstein, Meyer, & Evans, 2001).

The focus of the present study was to examine whether the ability to reconfigure the task sets is dependent on the number of stimuli involved in task switching. Our general assumption was that the efficiency to reconfigure task sets is influenced by the stimulus-set size (i.e., the number of *different* exemplars of a stimulus category). With a small number of stimuli the strength of associations between attributes of a stimulus category and motor response will get continuously stronger with increasing experience. Therefore, we expected that with increasing time on task, costs of switching between task sets would be more strongly reduced under switching conditions with smaller stimulus-set sizes than with larger stimulus-set sizes. The specific aims of this study were twofold: First, to investigate whether switch costs are more strongly reduced after practice under small stimulus-set size conditions. Second, to examine whether age differences in task switching are modulated by stimulus-set size. Given that reliable age differences in switch costs are sometimes found and sometimes not, we wanted to examine whether age differences in associative learning between tasks, stimulus categories, and responses might influence the magnitude of age differences in switch costs.

1.1. The measurement of task switching and the influence of stimulus-set size

So far different variants of task-switching paradigms have been used to measure the reconfiguration of task sets. For instance, in one of the first task-switching studies (Jersild, 1927), participants were asked to alternate between tasks A and B (e.g., addition and subtraction) in one condition (henceforth termed mixed-task blocks). In the other condition participants performed only one task throughout a block (henceforth termed single-task blocks). Switch costs were determined as the difference between performance in mixed and single-task blocks (cf. Allport et al., 1994; Brinley, 1965; Kray & Lindenberger, 2000;

hereafter termed *mixing costs*). A number of years ago, Rogers and Monsell (1995) introduced the alternating runs paradigm in which switch costs are determined within mixed-task blocks as the difference between performance on switch trials (switching from task A to B or vice versa) and on non-switch trials (repeating task A or B). The advantage of the alternating runs paradigm is that switch costs are measured within the same block. In contrast, switch costs that are measured by between-block comparisons (i.e., mixing costs) may also include differences in working memory load, arousal, and so forth (Rogers & Monsell, 1995). Nearly all of the task-switching studies have found within-block switch costs in terms of slowed mean reaction times and increased error rates on switch trials than on non-switch trials (hereafter termed *switch costs*).

It appears that switch costs are a robust phenomenon because they have been demonstrated across stimulus domains and different variants of the task-switching paradigm (for recent reviews, see Logan, 2003; Monsell, 2003). Task-switching costs can be reduced with practice and with increasing preparation time. For instance, Rogers and Monsell (1995) showed that the magnitude of switch costs was substantially decreased when the time to prepare for the next task was increased from 150 to 600 ms (termed *preparation effect*). Importantly, switch costs did not further decrease and did not disappear when the preparation time was enlarged to 1200 ms (termed *residual switch costs*). On the basis of a series of experiments they suggested that task-set reconfiguration (i.e., switch costs) consists of two components, an endogenous (anticipatory) component of task control, that can be partly executed in advance, and a stimulus-triggered component, that is triggered by the onset of the stimulus (Monsell, 2003; Rogers & Monsell, 1995). Interestingly, residual switch costs were still found after very extensive practice (e.g., Kray & Lindenberger, 2000) and extremely long preparation times (e.g., Meiran, Gotler, & Perlman, 2001). Note that residual switch costs have also been explained by a failure to engage in advance preparation (De Jong, 2001) or as a kind of proactive interference from the previous task (Allport et al., 1994).

However, there are some pre-conditions in order to measure switching at the level of "task sets". For instance, Rogers and Monsell (1995) argued that the number of stimuli " … must be large: Any combination must be experienced with a low enough frequency to make it unlikely that the participant will, during the course of the experiment, learn an association between attributes, task cues, and responses. Otherwise the participant may, through learning, redefine what the experimenter wishes to treat as two tasks, as one" (p. 211). Put differently, the use of small stimulus-set sizes in task-switching experiments may results in a modification of association strengths between tasks, stimulus attributes, and responses with increasing practice so that reconfiguration at the level of "task sets" is no longer necessary. To avoid associative learning during the course of the experiment, Rogers and Monsell (1995) used combinations between digits and letters (e.g., A4) as stimuli that allow creating sufficiently large stimulus-set sizes for each of the two involved tasks. Hence, the number of identical stimulus repetitions for each of the two tasks was rather low throughout the experiment.

There are a number of task-switching studies, however, that only use rather small stimulus-set sizes (e.g., 4 stimuli such as a red or green letter "A" and "S"). Here the number of stimulus repetitions throughout the experiment is extremely high, increasing the likelihood that participants learn associations between tasks, stimuli, and responses during the course of the experiment. If so and given that subjects have enough preparation time, residual switch costs might disappear with increasing practice. In the present experiment we will manipulate the stimulus-set size and examine whether the strength of associative learning between task components influences task switching.

1.2. Practice effects on task switching and aging

The second focus of this study was to investigate age differences in the reduction of switch costs as a function of stimulus-set size and practice. So far there is only some evidence that older adults have more difficulties than younger adults in learning associations between different stimulus features in memory tasks (Chalfonte & Johnson, 1996; Mitchell, Johnson, Raye, Mather, & D'Esposito, 2000) and between stimulus and rewards (Mell et al., 2005). However, nothing is known about whether age differences in associative learning might modulate age differences in task switching.

Generally studies on age differences in task switching found substantial age differences at the general level of task switching (i.e., in mixing costs; cf. Kramer & Kray, in press; Kray, Eber, & Lindenberger, 2004; Kray & Lindenberger, 2000; Mayr, 2001; van Asselen & Ridderinkhof, 2000; for a meta-analysis; see Verhaeghen & Cerella, 2002). Age differences in mixing costs were attributed to age-related impairments in maintaining and selecting of task sets (Kray & Lindenberger, 2000), or to age-related impairments in differentiating task sets under ambiguous conditions (Mayr, 2001). In contrast, results on age differences in switch costs are rather inconsistent. Some studies found that age differences in switch costs can also be explained by age differences in general speed of processing because reliable age by switch condition interactions disappeared when age differences in baseline performance (i.e., in non-switch trials) were taken into account (e.g., Bojko, Kramer, & Peterson, 2004; Kramer, Hahn, & Gopher, 1999; Kray et al., 2004; Kray & Lindenberger, 2000; Salthouse, Fristoe, McGuthry, & Hambrick, 1998; for a review, see Kramer & Kray, in press; for a meta-analysis, see Verhaeghen & Cerella, 2002). However, other studies obtained reliable age differences in switch costs, even after controlling for age differences in baseline performance, suggesting age-specific deficits in the reconfiguration of task sets (De Jong, 2001; Kray, Li, & Lindenberger, 2002; Mayr, 2001; Meiran et al., 2001).

One reason for the discrepancy in findings on age differences in switch costs could be the amount of practice given to younger and older adults. Thus, age differences in task-switching costs can be due to age differences in pre-experimental experience (i.e., negative cohort effects; e.g., less work-associated cognitive stimulation). Providing practice is one research strategy to reduce age differences due to negative cohort differences. So far only a few studies examined the effects of practice on age differences in task switching (Cepeda, Kramer, & Gonzalez de Sather, 2001; Kramer et al., 1999; Kray & Lindenberger, 2000). For instance, Kramer et al. (1999) found that age differences in switch costs disappeared with modest amounts of practice. Especially older adults showed large practice effects on switch trials in the first session of practice. In contrast, Kray and Lindenberger (2000) found that younger and older adults showed equivalent practice effects in switch costs after six sessions of practice (cf. Cepeda et al., 2001) whereas age differences in switch costs were already absent at pretest. One reason for this discrepancy in findings could be that in the latter study subjects already received one practice session before the pretest session. Furthermore, some of the aging studies that reported reliable age differences in switch costs used rather small stimulus sets of 4 or 8 stimuli (Mayr, 2001; Meiran et al., 2001), whereas studies that used large stimulus-set sizes (e.g., 400 stimuli; Kray & Lindenberger, 2000) did not obtain reliable age differences in switch costs. Hence, a further goal of this study was to examine whether younger and older adults show a similar reduction of switch costs under conditions of small and large stimulus-set sizes. Given that there is at least some evidence that older adults have impairments to form associations between stimulus features during learning (Chalfonte & Johnson, 1996; Mitchell et al., 2000), older adults may also be impaired in associating stimuli, tasks, and responses during task-switching, although stimulus-set size is rather small.

1.3. Response compatibility, task switching, and associative learning

Switching between task sets is also dependent on the overlap between the involved tasks at the level of stimulus and response sets (e.g., Mayr, 2001; Meiran et al., 2001; Rogers & Monsell, 1995). Switching costs are substantially reduced when the stimulus itself activates the currently appropriate task set (termed task cueing; cf. Rogers & Monsell, 1995). This is the case for univalent stimuli, which include a combination of a task-relevant attribute and an attribute not associated with each of the two tasks. In contrast, ambiguous or bivalent stimuli include a combination of attributes associated with the two different tasks involved in task switching, that is, only one attribute is currently relevant for the task at hand, while the other is not. For instance in the study of Rogers and Monsell, subjects were instructed to decide in one task whether letters belong to consonants or vowels, and in the second task, whether the digits were odd or even. Bivalent stimuli were all digit-letter combinations (e.g., B5) and univalent stimuli were combinations of a digit and a neutral stimulus (e.g., 5%) or combinations of a letter with a neutral stimulus (e.g., B#). Thus, in the absence of stimulus ambiguity (for univalent stimuli) the stimulus as such can activate task-appropriate behavior.

Ambiguity can also occur at the level of response sets when stimulus attributes of each of the two tasks are partly mapped onto the same response. This is the case when only two responses (usually left and right key press) are used in task-switching situations. In the context of task switching, facilitation can be found when the currently relevant attribute and the currently irrelevant attribute (the stimulus attribute associated with the other task) are mapped onto the *same* response (compatible response mappings). Interference can be found when the currently relevant attribute and the currently irrelevant attribute are mapped onto *different* responses (incompatible response mappings). Switching costs have been found to be somewhat smaller for compatible than incompatible response mappings (e.g., Meiran et al., 2001; Rogers & Monsell, 1995).

The effects of response compatibility will be examined in the present study for two reasons: First, we expected response compatibility to interact with stimulus-set size. Thus, when the same stimulus attributes are repeated over and over again, as in the small stimulus-set size condition, response priming from the currently irrelevant task feature should be much larger as compared to task contexts in which each stimulus occurs only a few times. Second, there is some evidence that older adults are impaired in task switching when response mappings are incompatible (Meiran et al., 2001; but see Kramer et al., 1999). Age differences in task switching are strongly reduced and disappear when there is no overlap between task attributes at the level of stimuli and responses (Mayr, 2001), supporting the view that older adults' problems in task switching are primarily due to deficits in differentiating among overlapping task sets. Thus, one might expect that older adults show practice effects on switching only for compatible response mappings, but not for incompatible response mappings.

2. This study

Task-switching performance was measured with a cue-based switching paradigm in which familiar words were presented successively on the screen (e.g., rabbit, chair, dog, letter, and so on). In one task (task A), participants were either instructed to decide whether the word belonged to the category of animals or not. In the other task (task B), they were asked to decide whether the number of syllables was equal to one or two. The participants performed both tasks either in isolation (in single-task blocks) or within the same block (in mixed-task blocks). Note that the time interval between cue and target presentation (CTI = 1100 ms)[1] as well as between the response and the next cue (RCI = 600 ms) were relatively long to provide enough preparation time and to avoid carryover effects from the preceding trial.

To examine age differences in task switching we compared a group of younger and older adults. Furthermore, to investigate the effects of stimulus-set size on task switching, one group received the same four stimuli (stimulus-set size = 4; henceforth termed 4-target group) throughout the experiment, and the other group received 96 different stimuli (stimulus-set size = 96; henceforth termed 96-target group). Practice effects were determined as the differences in performance between the first and the second half of the session, and response compatibility as the differences in performance between compatible trials (in which the two tasks call for the same response) and incompatible trials (in which the two tasks call for different responses). In sum, the experiment included five experimental factors: Two between-subjects factors, Age (younger vs. older) and Set size (4-target group vs. 96-target group), and three within-subjects factors, Switching (non-switch vs. switch trials), Practice (first half vs. second half), and Compatibility (compatible, incompatible). The following predictions were made: We expected that the 4-target group would show a greater reduction of switch costs with increasing practice than the 96-target group, suggesting that the strength of associative learning between tasks, stimuli, and responses facilitates task switching. Given that older adults may have major problems in separating overlapping task representations, younger and older adults should differ in the reduction of switch costs under small stimulus-set sizes as a function of response compatibility.

2.1. Method

2.1.1. Participants

A total of 65 adults participated in the experiment, 32 younger and 33 older adults. One elderly woman in the 96-target group was excluded from data analysis because her number of errors was more than three standard deviations above the group mean ($M = 26.3$, SE = 5.03). Nearly all of the younger participants were students at Saarland University who received course credit for participation. All other participants were recruited from a subject pool or by personal contact. The participants were paid 12€ (about $12 US) for a single-session experiment.

Table 1 displays the sample characteristics. Two psychometric tests were given to indicate the representativity of the selected sample, a prototypical measure of perceptual speed

[1] Note that some researchers found no reduction of switch costs when only *one* long CTI was used (Koch, 2001) or a smaller reduction of switch costs when the CTI was not varied (Altmann, 2004). To anticipate, however, we define such effects in the present study.

Table 1
Descriptive variables for younger and older adults seperately for the 4-target and the 96-target group

Variable	Younger adults				Older adults			
	4-target		96-target		4-target		96-target	
	M	SD	*M*	SD	*M*	SD	*M*	SD
n	16		16		16		16	
% Female	50		50		50		50	
Age	21.4	2.1	21.8	1.1	65.3	4.9	66.6	4.7
Digit-Symbol	61.8	9.4	61.0	9.7	41.7	7.7	43.8	9.2
Spot-a-Word	23.3	4.8	23.9	2.5	27.4	3.1	24.9	4.1

Note. For a description of the Digit-Symbol Substitution Test and Spot-a-Word test, see Section 2.1.1.

of processing (the Digit-Symbol Substitution test (DSST), adapted from Wechsler, 1982) and of semantic knowledge (the Spot-a-Word test; Lehrl, 1977; for a detailed description and internal consistencies of both tests, see Lindenberger, Mayr, & Kliegl, 1993). The Digit-Symbol Substitution test consists of a template, with nine digit-symbol mappings, and a test sheet that was enlarged to reduce problems related to poor vision or motor abilities. The participants were instructed to fill in the symbol that corresponds to the digit. The test score was the number of correct symbols after 90 s. The Spot-a-Word test was used to measure semantic knowledge. Thirty-five items containing one word and four pronounceable non-words were presented successively on the computer screen. The participants were instructed to find the word. The test score was the total number of words found.

A typical pattern of age effects was obtained in both tests: An age-related decline in the DSST performance, the older adults reached a significantly lower score than younger adults, $F(60) = 68.6$, $p < .01$, MSE = 81.2, $\eta^2 = .53$, and age stability/increase in the Spot-a-Word test in which older adults achieved a significantly higher score than the younger adults, $F(60) = 7.4$, $p < .01$, MSE = 13.8, $\eta^2 = .11$.

2.1.2. Materials and tasks

IBM compatible computer were used for data collection. The stimuli were presented on a CTX 17-inch color monitor with a black background. The experiment was controlled by the software package Experimental Run Time System (ERTS, Beringer, 2000).

On successive trials familiar words (i.e., familiar one-syllable or two-syllable nouns) were presented on the screen. In one task, participants were told to decide whether or not the word belonged to the category of animals. In the other task they had to decide whether the word consisted of one syllable or of two syllables. The same two response keys were employed for both tasks. Participants were asked to press the right response key when the word referred to an animal or when it was a two-syllable word; otherwise they had to press the left response key. On compatible trials attributes of both different tasks were mapped onto the same response, and on incompatible trials onto different responses.

Note that all stimuli (words) were ambiguous because they included attributes of each the two different tasks. The following attribute combinations were possible: animals/one syllable (e.g., CAT), animals/two syllables (e.g., RABBIT), non-animals/one syllable (e.g., CHAIR), or non-animals/two syllables (e.g., PENCIL). For the *4-target group* the stimulus-set size consisted of only 4 stimuli meaning that there was only one stimulus per attribute combination. For the other experimental group, the *96-target group*, the stimulus-set size consisted of a total of 96 different words; thus there were 24 different stimuli per attribute combination.

To indicate the currently relevant task (category or syllables), symbols (single letters) were used as task-set cues. The first letter of the German word "Kategorie" indicated the category task and the first letter of the German word "Silbe" the syllable task. Task-set cues and targets were displayed in an uppercase 34-bitmap "Swiss regular" font. A small sign above the keyboard indicated how the stimuli were mapped onto the responses to help participants remember the assignments.

2.1.3. Procedure

The session lasted approximately for 100 min. First, the Digit-Symbol Substitution test was administered. The younger and older adults were matched according to their DSST score and then assigned to one of the two experimental conditions (4-target vs. 96-target group). Subjects with similar DSST scores (± 3) were assigned to different experimental groups. Thereafter, the participants filled out a short demographic questionnaire, performed the Spot-a-Word test, and then the experimental tasks. All participants had a short break after about 50 min of testing.

Each experimental session began with a *practice phase* consisting of four blocks of eight trials each. Two of these were single-task blocks in which participants performed only the category tasks or the syllable tasks. In the other two blocks participants switched between the two tasks depending on the instructional cue (mixed-task blocks). Participants then performed 24 *experimental blocks*, 12 mixed-task blocks and 12 single-task blocks.

The order of experimental blocks was random with the restriction that the two single-task blocks (category, syllable) and two mixed blocks were grouped together. This sequence of blocks was constant across subjects and experimental conditions while the sequence of trials within each block was varied across subjects.

Each *block* consisted of 33 trials, yielding a total of $33 \times 24 = 792$ trials. The first trial in each block was not analyzed; this trial was drawn from a pool of practice stimuli that did not overlap with the pool of experimental stimuli. The single and mixed blocks consisted of an equal number of the two response types (left, right) and four attribute combinations (animal/one syllable, non-animal/one syllable, animal/two syllables, non-animal/two syllables). In addition, mixed-task blocks consisted of an equal number of non-switch and switch trials.

Each *trial* started with a task cue (K, S) that remained for 300 ms, followed by a constant time interval of 800 ms. The target was presented until the response was made. The time between response and appearance of the next task cue was also fixed to 600 ms.

Participants were told to respond as quickly and as accurately as possible. Before each of the experimental blocks an instruction window appeared that indicated whether the syllable task, the category task, or both tasks have to be performed in the following block. After each experimental block, feedback regarding the subject's mean response times and percentage of errors was given.

2.2. Results

The analysis was based on log-transformed RTs for correct responses and on errors. RTs shorter than 180 ms and longer than 3700 ms (1.1% of the responses) were excluded from data analysis.

Table 2
Analysis of variance results for reaction times by Age, Set size, Switch, Compatibility, and Practice

Variable	*F*	*p*
Age	50.79	.000**
Set size	4.53	.037*
Age × Set size	8.71	.004**
Switch	64.15	.000**
Switch × Age	2.29	.135
Switch × Set size	0.82	.370
Switch × Age × Set size	2.05	.158
Compatibility	40.06	.000**
Compatibility × Age	0.31	.579
Compatibility × Set size	11.13	.002**
Compatibility × Age × Set size	1.53	.221
Practice	148.77	.000**
Practice × Age	2.76	.101
Practice × Set size	0.01	.987
Practice × Age × Set size	2.44	.124
Switch × Compatibility	1.59	.212
Switch × Compatibility × Age	0.26	.610
Switch × Compatibility × Set size	8.42	.005**
Switch × Compatibility × Age × Set size	0.05	.824
Switch × Practice	0.02	.898
Switch × Practice × Age	4.61	.036*
Switch × Practice × Set size	21.60	.000**
Switch × Practice × Age × Set size	0.42	.519
Compatibility × Practice	3.78	.057+
Compatibility × Practice × Age	0.08	.775
Compatibility × Practice × Set size	1.43	.237
Compatibility × Practice × Age × Set size	0.13	.719
Switch × Compatibility × Practice	0.07	.799
Switch × Compatibility × Practice × Age	2.02	.161
Switch × Compatibility × Practice × Set size	2.84	.097
Switch × Compatibility × Practice × Age × Set size	6.11	.016*

* $p < .05$.
** $p < .01$.
\+ $p < .10$.

An ANOVA was conducted with two between-subjects factors Age (younger vs. older) and Set size (4-target vs. 96-target group), and three within-subjects factors Switching (non-switch, switch), Compatibility (compatible, incompatible), and Practice (first half vs. second half). Results of ANOVA are displayed in Table 2.[2] The means of all experimental conditions are displayed in Table 3.

Table 2 indicates that all main effects were significant. We found a significant main effect of age, $F(1,60) = 50.79$, $\text{MSE} = 0.470$, $p < .001$, $\eta^2 = .41$, indicating that older adults responded slower than younger adults; a significant effect of set size, $F(1,60) = 4.53$, $\text{MSE} = 0.470$, $p < .05$, $\eta^2 = .04$, suggesting that responding was slower for a large set size; reliable switch costs, $F(1,60) = 64.15$, $\text{MSE} = 0.610$, $p < .001$, $\eta^2 = .30$, which showed that responding was slower on switch than on non-switch trials; a significant effect of practice,

[2] Although all analyses in this study were based on log-transformed RTs, we display the means of raw RTs in addition, because they are more familiar to most readers.

Table 3
Means for Log-transformed RTs, RTs, and Percent Error Scores

Age group/ Target group	Practice	Compatibility	Log-transformed RT		RT		% errors	
			Non-switch	Switch	Non-switch	Switch	Non-switch	Switch
Younger adults/ 4-Target group	First half	Compatible	6.413	6.500	674	745	1.88	2.65
		Incompatible	6.480	6.575	720	811	1.30	0.83
	Second half	Compatible	6.183	6.248	510	551	0.61	1.97
		Incompatible	6.311	6.277	599	567	2.92	1.36
Younger adults/ 96-Target group	First half	Compatible	6.745	6.801	969	1042	1.69	2.64
		Incompatible	6.749	6.784	979	1008	1.82	0.71
	Second half	Compatible	6.545	6.605	781	842	0.54	1.76
		Incompatible	6.561	6.660	785	882	3.53	1.90
Older adults/ 4-Target group	First half	Compatible	7.008	7.155	1259	1469	1.76	2.44
		Incompatible	7.087	7.169	1366	1468	2.15	0.87
	Second half	Compatible	6.784	6.888	986	1106	0.59	1.83
		Incompatible	6.847	6.936	1054	1164	3.05	2.24
Older adults/ 96-Target group	First half	Compatible	7.069	7.093	1322	1361	1.93	4.21
		Incompatible	7.071	7.111	1339	1381	3.52	0.75
	Second half	Compatible	6.724	6.804	930	1001	1.17	2.03
		Incompatible	6.745	6.858	953	1059	4.40	3.66

$F(1,60) = 148.77$, MSE = 0.049, $p < .001$, $\eta^2 = .68$, indicating that responding was faster in the second than the first session of practice, and a significant effect of compatibility, $F(1,60) = 40.06$, MSE = 0.005, $p < .001$, $\eta^2 = .73$, indicating that responding was faster on compatible than on incompatible trials.

In addition, we found a number of significant two- and three-way interactions (see Table 2). As the five-way interaction between Age, Set size, Switching, Practice, and Compatibility was also found to be significant, $F(1,60) = 6.11$, MSE = 0.003, $p < .05$, $\eta^2 = .09$, separate ANOVAs were conducted for the 4-target and 96-target group and for younger and older adults to understand the nature of this interaction.

4-target group: Results of the ANOVA indicated significant two-way interactions between Age and Switching: $F(1,30) = 6.06$, MSE = 0.007, $p < .01$, $\eta^2 = .06$, Switching and Practice: $F(1,30) = 8.74$, MSE = 0.004, $p < .01$, $\eta^2 = .21$, and Switching and Compatibility: $F(1,30) = 7.05$, MSE = 0.004, $p < .01$, $\eta^2 = .19$. Moreover, the four-way interaction between Age, Switching, Practice, and Compatibility was also significant: $F(1,30) = 9.24$, MSE = 0.003, $p < .01$, $\eta^2 = .22$. Therefore, we conducted separate ANOVAs for compatible and incompatible trials.

For compatible trials the interactions between Age and Switching and between Switching and Practice were marginally significant, $F(1,30) = 2.89$, MSE = 0.007, $p = .09$, $\eta^2 = .03$; $F(1,30) = 3.58$, MSE = 0.002, $p = .06$, $\eta^2 = .10$, respectively; (see Fig. 1, at the top) whereas the interaction between Age and Practice did not approach significance ($p = .93$). In contrast, for incompatible trials we found significant greater practice benefits for younger adults than for older adults, Age × Practice: $F(1,30) = 5.33$, MSE = 0.005, $p < .05$, $\eta^2 = .09$. Switch costs were reduced with practice, Switching × Practice: $F(1,30) = 6.89$, MSE = 0.006, $p < .01$, $\eta^2 = .15$, but this interaction was modulated by age. That is, we obtained a triple interaction between Age, Switching, and Practice, $F(1,30) = 8.58$, MSE = 0.006, $p < .01$, $\eta^2 = .19$, suggesting that the

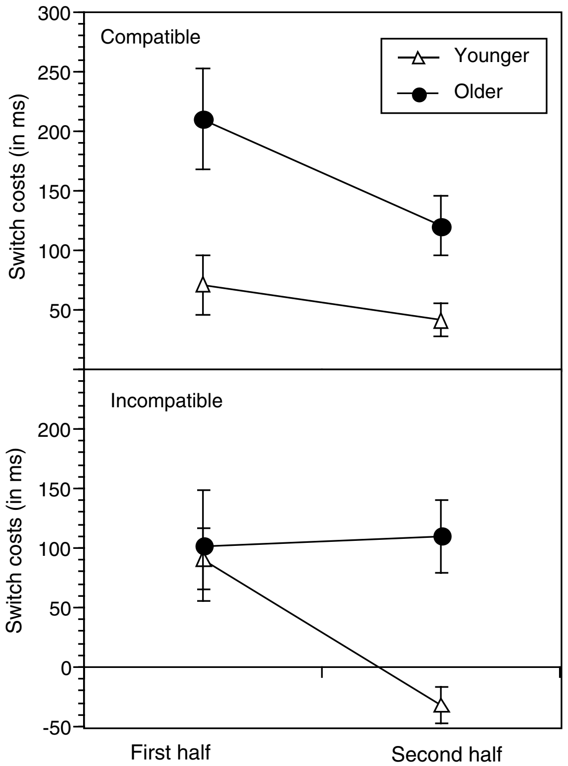

Fig. 1. Switch costs (in ms) as a function of age (younger vs. older) and practice (first half vs. second half) for compatible trials (at the top) and for incompatible trials (at the bottom) for the 4-target group. Error bars refer to the standard errors.

reduction of switch costs with practice on incompatible trials was more pronounced for younger than for older adults (see Fig. 1, at the bottom).

96-target group: For this group the ANOVA revealed two significant interactions, one between Switching and Practice, $F(1,30) = 13.72$, $\text{MSE} = 0.004$, $p < .01$, $\eta^2 = .30$, indicating that practice benefits were larger on non-switch than on switch trials ($M = 295$ ms vs. $M = 261$ ms, respectively). The second was found between Compatibility and Practice, $F(1,30) = 5.07$, $\text{MSE} = 0.0001$, $p < .01$, $\eta^2 = .08$, that is, practice effects were larger for compatible than incompatible trials. Most important, in contrast to the group with a small stimulus-set size (see Fig. 2), the results indicated no significant interaction between Age and Switching ($p = .96$), and between Age, Switching, Practice, and Compatibility ($p = .50$).

Separate analysis for the *young age group* showed a significant higher-order interaction between Set size, Switching, Practice, and Compatibility, $F(1,30) = 7.89$, $\text{MSE} = 0.006$, $p < .01$, $\eta^2 = .20$, therefore separate analyses were conducted for the 4-target and 96-target groups. Only for the 4-target group we found significant interactions of interest between Switching and Compatibility, $F(1,30) = 4.64$, $\text{MSE} = 0.0001$, $p < .05$, $\eta^2 = .23$, and Switching and Practice, $F(1,30) = 13.11$, $\text{MSE} = 0.004$, $p < .01$, $\eta^2 = .45$. Moreover, we found a significant triple interaction between Switching, Compatibility, and Practice, $F(1,30) = 511.03$, $\text{MSE} = 0.002$, $p < .01$, $\eta^2 = .42$, suggesting that practice effects on switch costs were larger

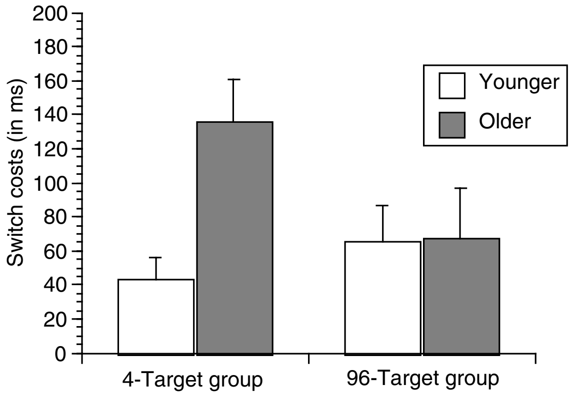

Fig. 2. Switch costs (in ms) as a function of age (younger vs. older) and stimulus-set size (96-target group vs. 4-target group). Error bars refer to the standard errors.

for incompatible than compatible trials. In contrast to younger adults, for *older adults* none of these interactions approached significance.

Error analysis. To analyze age differences in error rates we conducted the same ANOVA as for the analysis of latencies. We obtained significant interactions between Switching and Compatibility, $F(1,30) = 44.71$, $\text{MSE} = 4.343$, $p < .001$, $\eta^2 = .42$, and Practice and Compatibility, $F(1,30) = 45.19$, $\text{MSE} = 4.351$, $p < .001$, $\eta^2 = .42$. Response compatibility effects were larger in the second half of the session and on non-switch trials. Importantly, error rates did not significantly differ between the 4-target and 96-target groups ($p = .26$) and, there was no significant interaction between Age and any other experimental variable, suggesting that the observed age effects in latencies were not modulated by age differences in error rates.

2.3. Summary

Results of this experiment showed that age differences in practice effects on task switching interacted with stimulus-set size and response compatibility. Under conditions of small stimulus-set size, age differences in the reduction of switch costs with practice were modulated by response compatibility. Only for incompatible trials, in which attributes of both task sets were mapped onto different responses, younger and older adults significantly differed in practice benefits on switch costs. Younger, but not older adults, showed a greater reduction of switch costs with practice on incompatible than on compatible trials. For compatible trials, in which attributes of both task sets were mapped onto the same response, and by this response interference is reduced, younger and older adults showed a similar reduction of switch costs. It is also important to note that age differences in task switching only approached significance for incompatible trials. Thus, older adults showed greater switching costs only when there was interference at the level of response sets. Interestingly the response compatibility effect as such interacted with task switching only under conditions with small stimulus-set size. Hence, response priming from the currently irrelevant task sets is stronger and increases costs of switching when the same stimulus is repeated over and over again during the course of the experiment.

Under switching conditions with large stimulus-set size we failed to find significant age differences in switching costs or any other reliable interaction with age. Younger and older adults showed similar benefits on task performance with practice. In contrast to conditions with small stimulus-size, practice benefits were larger on non-switch than on switch trials. In addition, we found larger practice effects on compatible than on incompatible trials, but no interactions with task switching. Thus, the effects of stimulus-set size on age differences in task switching seems to depend on a combination of practice and response interference, as will be discussed in the following.

3. General discussion

The goal of the present study was to examine the role of associative learning for the ability to flexibly switch between task sets. Considering Rogers and Monsell's view that task-switching studies should include a large number of stimuli in order to avoid associative learning, because otherwise subjects may redefine the task-set instructions, we manipulated stimulus-set size in this study. We expected a greater reduction of switch costs for the group with a small stimulus-set size since associative learning should facilitate task switching. Moreover, we expected that associative learning would modulate age differences in task switching, as reliable age differences in switch costs were often found in studies that used small stimulus-set sizes. Some results of our study indeed support these views.

First, one of the most interesting findings was that older and younger adults were able to reduce costs of switching with practice when the stimulus-set size was small but this effect was further modulated by the compatibility of responses. For compatible trials in which the stimulus attributes of the two task sets were mapped onto the same response, either left or right, younger and older adults did not differ in the reduction of switch costs (see Fig. 1). In contrast, for incompatible trials in which stimulus attributes of the two task sets were associated with different responses, we obtained reliable age difference in the reduction of switch costs, that is, the reduction of switch costs was substantially greater for younger than for older adults (see Fig. 1). This finding is consistent with the idea that older adults are primarily impaired in flexibly switching between tasks when there is interference at the level of stimulus- and response sets. Thus, it seems that older adults, although they responded to each of the four stimuli about 200 times, still had problems to differentiate among overlapping stimulus- and response sets, and therefore did not profit from associative learning. However, given that we had no "neutral" condition for response compatibility in the present experiment we cannot exclude the alternative interpretation that older adults did not learn to inhibit currently task-irrelevant features.

The second noteworthy finding is that age differences in task switching were only present for the group with the small stimulus-set size and not for the group with the large stimulus-set size. Older adults only showed significantly greater switch costs than younger adults when rather few stimuli were included (see Fig. 2). This is consistent with observations that age differences in switch costs are often found in studies that work with small set sizes (e.g., Mayr, 2001; Meiran et al., 2001), but not with large set sizes (e.g., Kray & Lindenberger, 2000).

Moreover, age differences in switch costs under small set size conditions were primarily found for incompatible trials (for compatible trials only in tendency), which is generally consistent with the view that older adults had problems to differentiate or to separate stimulus-and response attributes of the two tasks. If so, switching between the same four stimuli during the course of the experiment may produce large negative transfer of learning. There are some researchers who supposed that switch costs are the result of a negative transfer of learning meaning that an earlier performed S–R mapping in one task can interfere with the implementation of a new task (e.g., Allport & Wylie, 2000). Put differently, the present S–R association can trigger retrieval of previously learned S–R associations. The retrieval of S–R associations within a task results in positive priming and across tasks in negative priming. Along this line Waszak and colleagues (2003) recently observed that switching to the other task was substantially slowed when the present stimulus appeared as a distracter in the other task, even if this event happened more than 100 trials earlier. These findings suggest that associations between stimulus- and response attributes of one task, created on previous events, influence the switching to a new task, even without long lasting learning processes, whenever subjects have to make a choice between two task sets. In this context, it is interesting to note that in the present study response compatibility interacted with the set size condition. Response priming was larger when subjects retrieved the same S–R mappings several times under small set size conditions than under large set size conditions. Thus, the presence of large response priming for small set sizes and the fact that older adults had problems to overcome negative priming of currently irrelevant task features during switching seems to produce age differences in task switching primarily in the 4-target but not in the 96-target groups.

Third, following theoretical considerations by Rogers and Monsell (1995) we started this study with the idea that small stimulus-set size facilitates the learning of associations between stimulus attributes, tasks, and responses. As a consequence, subjects may redefine task-set instructions and switching on the level of task sets is no longer necessary. For instance, on compatible trials subjects may be able to integrate stimulus attributes of the two tasks into one, so that the stimulus as such is directly linked to the left or right response. According to attentional control models, the application of such stimulus–response rules becomes automatized with modest amount of practice and the stimulus itself can activate the appropriate response without attentional control. On the one hand the results of this study are consistent with this view as we obtained a reduction of switching costs with practice for compatible trials. On the other hand the results are inconsistent with the idea as we still observed reliable switch costs after practice for compatible trials (see Fig. 1). However, although the forming and application of S–R associations is assumed to be a fast process it might be that more practice, at least more than in the present study, is needed before costs of switching fully disappear.

In contrast, for incompatible trials a separation of both task sets appears more useful than the integration because stimulus features are linked to different responses depending on the task. Older adults were less able to benefit from practice and to reduce switching costs when the separation of both task sets is needed and the currently irrelevant task feature had to be suppressed. Surprisingly, for the younger group practice benefits on switching were larger for incompatible than compatible trials and negative switching costs were found after practice. One possible explanation is that younger adults find an effective way for decoupling the tasks on incompatible trials by defining less overlapping S–R rules for the two tasks. Defining distinctive rules for both tasks may help them to switch without interference.

A somewhat unexpected finding was that we found greater practice effects on non-switch than on switch trials with a large stimulus-set size. Given that under large stimulus-set size conditions the influence of associative learning between task components is much smaller as each stimulus is repeated only a few times it may be less surprising that practice effects occur first or to a greater extent on non-switch than on switch trials after modest amount of practice. Thus, we expect a reduction of switch costs when more practice is provided as shown in other studies (e.g., Kray & Lindenberger, 2000).

Finally, notetable is also that with large stimulus-set sizes response compatibility was substantially smaller. Thus, positive and negative response priming is largely reduced when each stimulus occurred only a few times throughout the experiment. For the 96-target group each stimulus appeared 8 times and 4 times in each half. Note that this finding is quite consistent with results of a recent study that examined the role of priming for the reconfiguration of task sets (Waszak, Hommel, & Allport, 2005). The authors found evidence for the view that switch costs can be partly a result of two separable priming processes that influence the reconfiguration of task sets. One is a negative priming process reflecting impaired switching when the stimulus includes an attribute that was previously suppressed, and the other is a so-called competitor priming process meaning that previous experience in one task affect switching performance to the other task. Importantly for the present context, Waszak and colleagues found that the negative priming effect was influenced by stimulus-set size. With a large stimulus-set size negative priming was much smaller than with a small stimulus-set size, suggesting that the suppression of distractions only affects task switching when distracters are highly activated (by large number of stimulus repetitions under small set size conditions). Similarly, priming studies also found that stimulus-set size affects negative priming, whereas robust negative priming effects were restricted to small set sizes (Malley & Strayer, 1995; Strayer & Grison, 1999).

We think that our findings have some implications for the study of task switching. Usually the reason for using very simple tasks to measure task switching is to reduce the variance associated with other factors such as the types of stimuli, type of tasks, and response types, and so on. However, in our view the "costs" of using only very few stimuli in task-switching studies are that because of the high number of stimulus repetitions, effects of positive and negative priming of the currently irrelevant task can interact with other variables of interest. As shown in the present study, it appears that older adults' impairments in task switching occur primarily when the currently relevant task has to be ignored (on incompatible trials). If response interference is also enhanced by use of small set sizes, then it is more likely to observe age differences in task switching with small than with large set sizes.

To summarize, we found that practice effects on switch costs were larger for small than large stimulus-set sizes, supporting the view that the strength of associations between stimuli, tasks, and responses influences the efficiency of task switching. Furthermore, older adults, as compared to younger adults, were not able to reduce switch costs under small set size conditions for response incompatible trials, which is consistent with the view that older adults problems' in task switching primarily occur when overlapping task-set representations need to be separated.

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