Age Differences in the Selection of Mental Sets: The Role of Inhibition, Stimulus Ambiguity, and Response-Set Overlap

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Switching between tasks leads to response-time (RT) costs at switch points (local switch costs) and often to RT costs at no-switch transitions that occur in the context of a task-switching block (global set-selection costs). With trial-to-trial cuing of tasks, moderate age effects were obtained for local switch costs, but large age effects were obtained for global selection costs. In Experiment 1, set-specific inhibition was found to be at least as large in old as in young adults, thus ruling out an inhibition deficit as a reason for age differences in global costs. In Experiment 2, large age differences in global costs were limited to conditions of ambiguous stimuli and full response-set overlap. This pattern of results suggests a greater reliance on set-updating processes in old than in young adults. The role of these processes is to ensure unambiguous internal control settings when ambiguity arises from stimuli and response specifications.

Aging has often been associated with deficits in higher level (executive) control. For example, behavioral evidence points to overproportional performance decrements when information flow needs to be coordinated across processing steps (Mayr & Kliegl, 1993; Mayr, Kliegl, & Krampe, 1996; Verhughe, Kliegl, & Mayr, 1997). Also, neurocognitive results indicate that the frontal lobes, often linked to executive control, seem to be more susceptible to age-related changes than are other brain areas (for reviews, see Phillips & Della Sala, 1998; West, 1996). Despite these indications of age-specific decline in high-level control, the nature of such a deficit is far from clear, and also, the degree to which it can be dissociated from possible lower-level age-related changes remains an unresolved issue. In addition, the search for a clearer characterization of age-related control deficits is hampered by the lack of a coherent general model of executive control (Monsell, 1996).

The so-called task-switching paradigm promises progress on this front (e.g., Allport, Styles, & Hsieh, 1994; Meiran, 1996; Rogers & Monsell, 1995). The main feature of this paradigm is the direct contrast between a condition in which high-level control settings (task sets) need to be changed across successive trials and one in which they are invariant. The idea is that when a change in task set is required, executive control processes that activate the current set or deactivate the preceding set become relevant. Thus, performance decrements in terms of both response times (RTs) and accuracy that occur at switch points (i.e., the so-called switch cost) are assumed to reflect processes that provide on-line control of high-level control settings.

Given the proposed age-related deficits in executive control, old adults would be expected to show increased switch costs. However, data on aging and task switching typically suggest age invariance or only moderately increased switch costs, at least when taking into account the possible effect of general slowing (Brinley, 1965; Hartley, Kieley, & Silbach, 1990; Kramer, Hahn, & Copher, 1999; Kray & Lindenberger, 2000; Mayr & Kliegl, 2000a; Saltz, Fristoe, McGuthry, & Hambrick, 1998). Thus, there is surprisingly little evidence that processing costs at switch points are particularly sensitive to aging.

Aside from the local switch cost, there is another, less appreciated indicator of processing constraints in task-switching situations. When comparing response times from single-task blocks with those from task-switching blocks, one finds general RT costs that occur even on trials that do not require a switch (i.e., Fagt, 1994; Meiran, 2000a). These costs are called here global set-selection costs to set them apart from the local switch costs that occur at set-transition points. The hypothesis to be tested in this article is that global set-selection costs reflect a processing mode that the cognitive system needs to adopt when operating in a set-selection situation and that may be particularly problematic for old adults. As reviewed in the next section, existing evidence seems at least generally consistent with the claim of age differences in global set-selection costs. Putting this claim on more solid empirical grounds and exploring some of its theoretical implications are the main goals of this article.

Global Set-Selection Costs

The most systematic examination of age differences in both local and global selection costs was undertaken in a study by Kray and Lindenberger (2000). In the task-selection condition of that study, participants had to switch tasks every two trials without the aid of external task cues. This condition was compared with single-task blocks in which only one of the possible tasks was relevant throughout. A large age-continuous sample was used in this study, along with six sessions of practice and three different pairs of tasks, thus ensuring generalizability of results across levels.

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of experience and task domains. One important result was that
global selection costs and local switch costs could be differentiated
into two related but clearly distinguishable psychometric factors,
suggesting functional dissociation between the two variables
within both younger and older adults. Even more important in
the current context was that age effects in global selection costs were
much larger than age effects in local switch costs across all task
combinations and the six practice sessions.

This result lends credence to the suggestion that older adults
have problems in set-selection situations that may not be repre-
sented in local switch costs. However, when it comes to the
question as to what kind of process is represented in global
selection costs, the Kray and Lindenberger (2000) study leaves
several possibilities. For example, twice as many stimulus-
response (S–R) associations were required in the task-switch con-
tion than in the single-task condition, so working-memory ca-
pacity may have been overtaxed in older adults. Also, participants
had to keep track internally of the sequence of tasks, a demand
that, again, may have led to greater working-memory demands in
switch blocks compared with single-task blocks.

A recent study by Keele and Ralaf (2000) demonstrates among
other things that working-memory-based explanations are not the
only possible accounts of global costs. These authors assessed
switch costs and global selection costs in frontal patients. They
used a paradigm in which tasks were cued on a trial-by-trial basis
(i.e., thus eliminating sequencing demands), and as a control to the
set-selection condition, they used a situation in which the same
number of S–R rules was required as in the task-selection condi-
tion (i.e., thus eliminating the S–R rule load confounded). It is
interesting to note that a very large global set-selection cost was
obtained that was limited to left-frontal patients, whereas local
switch costs did not differ across groups. Thus, at least in partic-
ular patient groups, it is possible to find global set-selection costs
even when working-memory demands play no obvious role. More-
over, these results also suggest a potential neural basis for global
costs and therefore render them a particularly interesting compo-
nent for further investigation.

What could be the functional reason for such costs? I propose in
this article that global costs could be indicative of processes
involved in updating an internal control setting in the face of actual
or potential interference between sets. According to this view,
increased global costs may reflect a deficit in terms of maintaining
a reliable representation of the currently relevant mental set when
stimulus information is ambiguous. Unreliable, fuzzy control set-
tings, in turn, enforce a larger reliance on updating processes that
reset the internal representation to reflect the current plan of action.

Keele and Ralaf (2000) suggested a particular variant of this view.
These authors proposed that an inhibitory deficit on the level of
mental sets may lead to an increase in interference from the
currently irrelevant set that then would have to be resolved by
additional updating processes. Thus, if frontal patients and possi-
bly also older adults have an inhibitory deficit, then additional
time may be needed on every trial to select between relevant and
irrelevant task representations that are insufficiently suppressed.
Given the age-related inhibition deficit proposed by Hasher,
Zacks, and May (1999), this seems a viable hypothesis, at least for
older adults.

The work by Kray and Lindenberger (2000) and, indirectly, also
the results reported by Keele and Ralaf (2000) suggest that global
selection costs may be indicative of an age-related executive
control deficit. At the same time, there are a number of studies in
which global costs were assessed either explicitly (Salthouse et al.,
1998) or "accidentally" by contrasting switch and no-switch trials
in a blocked manner (e.g., Brinley, 1965; Mayr & Kliegl, 2000a)
and in which no age effect was found in global costs (nor in local
switch costs, which in this paradigm cannot be dissociated from
global costs). Thus, aside from a replication of the basic result
obtained by Kray and Lindenberger (2000) that will be attempted
in Experiment 1, it is also important to identify factors that may
contribute to the inconsistencies in the literature. This is one of the
goals of Experiment 2.

**Experiment 1: Set-Selection Costs**

The main goal of this experiment was to replicate the results by
Kray and Lindenberger (2000) while avoiding at least some of the
ambiguities present in that study. Specifically, a task-euning para-
digm was used here in which tasks changed randomly on a trial-
by-trial basis. A verbal task label specifying which task set was
currently relevant was presented 600 ms before each stimulus. This
procedure eliminates sequential demands present in the alternate-
tasks paradigm (Kray & Lindenberger, 2000). Another advantage of
this paradigm was that because of the random selection of sets,
it was possible to trace the development of general selection costs
across up to three repetitions within the same mental set (with
more repetitions, the number of observations would become too
small). The reason why this is important is that age differences in
selection costs may be an expression of a slowed adaptation to
particular task demands across successive trials within the same
task. Meiran (1996) provided evidence that at least in certain
situations, such micropractice occurs across repeated no-switch
trials. If micropractice is much faster in young adults than in old
adults, then this could become manifest as an age-related global
set-selection cost. If, on the other hand, age differences in set-
selection costs do not seem to converge in the direction of single-
task RTs across successive same-task repetitions, then microprac-
tice as a possible explanation of global costs can be rejected.

A second goal of Experiment 1 was to examine to what degree
a lack of task-set inhibition may be a cause of age-related set-
selection deficits (e.g., Keele & Ralaf, 2000). Mayr and Keele
(2000) proposed that set switching is accompanied by a so-called
backward-inhibition process that suppresses the no-longer-relevant
set. They also proposed a paradigm for assessing backward inhibi-
tion. It is based on the assumption that switching back to a
mental set that was abandoned recently should take longer than
switching back to a mental set that was abandoned less recently
because of the greater residual inhibition associated with the more
recently abandoned set. Thus, for example, after switching from a
color-discrimination task to a shape-discrimination task, it should
take longer to switch back to the color task than to a third possible
task that was less recently used (see Figure 1). Note that this
prediction runs counter to predictions from activation-only theo-
reries of cognitive control, which would have to assume facilitation
for more recently used mental sets. Mayr and Keele reported a
series of experiments that clearly demonstrated the existence of
such an inhibitory process. They also provided evidence that even
though this process may be linked to executive control (i.e., it
occurs only when mental sets are activated in a top-down manner; Experiment 3), it is a rather low-level process that cannot be easily influenced by top-down control (Experiment 5).

To summarize, in this first experiment, both local switch costs and global set-selection costs were assessed with a task cuing paradigm. A cue-stimulus interval (CSI) of 600 ms was used that in past work has proven long enough for task-set preparation to be complete (e.g., Rogers & Monsell, 1995). In other words, the interest was in processes that occur after complete knowledge about what to do is available. Further, to be able to look at age differences in backward inhibition, three different tasks (discriminating the color, size, or shape of an object) were used. Three tasks were necessary to allow a contrast between trial-to-trial transitions in which a switch occurred to a task abandoned recently (i.e., a color-shape-color sequence) with transitions in which a switch occurred to a task not abandoned recently (i.e., a size-shape-color sequence).

Method

Participants. Twenty-four older adults (M = 71.0 years, SD = 3.3; 10 women and 14 men) and 24 younger adults (M = 20.1 years, SD = 0.9; 13 women and 11 men) participated in this experiment. Young adults were either students at the University of Potsdam or 13th-year students from a nearby high school. Older adults were selected for having participated in higher education (years of education are not comparable given the changes in educational systems due to historical changes in the former East Germany). In a multiple-choice vocabulary test (Lehrh, 1977), older adults showed superior performance compared with young adults (old, M = 33.2, SD = 1.4; young, M = 30.7, SD = 1.9), t(46) = 5.26, p < .01. In the Digit Symbol Substitution test (Wechsler, 1964), we found the usual pattern of young adults outperforming old adults (old, M = 48.3, SD = 8.1; young, M = 60.1, SD = 7.0), t(46) = 5.8, p < .01. Participants received a compensation of DM 12 (about $6).

Tasks and stimuli. Stimulus presentation occurred on a 17-in. (43.2 cm) Macintosh monitor. Within a white stimulus frame (side length = 20 mm), the stimulus object was presented centrally on a black background and was a circle or a square, red or green, and small (5 mm wide and tall) or large (10 mm wide and tall). A task cue indicating the currently relevant stimulus dimension (i.e., form, color, or size) was presented immediately above the stimulus frame. The left-arrow key on the standard Macintosh keyboard had to be pressed for circles and for green or small objects; the right-arrow key had to be pressed for squares and for red or large objects. The left and right index fingers were used for responding. In case of an error, the word Error appeared for 200 ms.

Procedure. Within each trial, the task cue was presented 50 ms after the response to the preceding stimulus (RCI = response-cue interval) and 600 ms before the next stimulus (CSI). Task cue and stimulus object disappeared together with the response; however, the stimulus frame was present throughout (see also Figure 1).

Twelve blocks of 80 trials were presented. In the first three blocks, each of the three tasks was presented once alone. Also, each of these blocks was preceded by a 20-trial practice block that could be repeated on demand. Blocks 4–12 were task-switching blocks in which tasks were selected randomly without constraints on a trial-by-trial basis. Before Block 4, there was another 20-trial practice block that could be repeated on demand. Each block was introduced by an instruction on the screen that informed about the in-principle relevant tasks.

Note that in this procedure, the comparison between single-task blocks and task-switching blocks (i.e., the critical contrast for global selection costs) may be biased: First, single-task blocks were always at the beginning of the session, and overall, participants received more practice with set-selection blocks than with single-task blocks. However, this procedure appeared defendable because it was geared toward efficient performance in the difficult set-selection situation so that the biases should work against the detection of global selection costs. Also, Experiment 2 replicated the central results from Experiment 1 even though no comparable bias was present there.

Results and Discussion

Correct RTs after at least two successive correct trials were retained for further analysis. Within each age group, all RTs larger than 99.5% of that age group’s RT distribution were discarded (i.e., old adults, RTs > 3,651 ms; young adults, RTs < 1,773 ms). Accuracy was generally high, with old adults (M = 97.8%, SD = 1.4) being slightly more accurate than young adults (M = 96.1%, SD = 1.4), t(1, 46) = 11.7, MSE = 840.7, p < .01. Interactions between age and any of the experimental factors were far from significant. Also, all accuracy effects were in the same direction as RT effects. Therefore, further reports on accuracy data are omitted.

To adequately capture both global set-selection costs and local switch costs, single-task trials were compared with set-selection trials. The latter category of trials was classified into four subcategories: switch trials, first set repetitions, second set repetitions, and third set repetitions. Finally, full appraisal of the switch effect requires consideration of an additional factor, namely, whether or not a response repetition occurs across successive trials. Past research has shown that local switch effects are modulated substantially by this factor (e.g., Mayr & Keele, 2000; Meiran, 1996;
Quinlan, 1999; Rogers & Monsell, 1995). Specifically, it seems that part of the total switch effect can be attributed to a large positive priming that occurs when both the task and the response repeat but that is eliminated or even reversed when responses repeat on switch trials. Thus, both response and set transitions need to be considered to distinguish actual set switch costs from set-specific response facilitation. An analysis of variance (ANOVA) was computed with age as a between-subjects factor, response repetitions versus nonrepetitions as a within-subject factor, and four additional, orthogonal, within-subject contrasts. The first, the global-cost contrast, tested the mean of all task-selection conditions against the single-task condition. The switch contrast tested the switch condition against the mean of all three no-switch conditions, the first-repetition contrast tested the first set repetition against the mean of the remaining two set-repetition conditions, and finally, the second set repetitions were tested against the third set repetitions. To guard against interpreting Age X Condition interactions as specific effects when they actually could be attributed to global slowing, we also conducted all analyses with log-transformed RTs. Unless reported otherwise, all significant, theoretically critical age effects were significant at least at the p = .01 level also for log RTs.

Global selection costs. Figure 2 shows all relevant data (see also Appendix A). Global set-selection costs were found for both age groups, F(1, 46) = 274.7, MSE = 19.393.4, p < .01, but these costs were much larger for old adults than for young adults (old, M = 412 ms; young, M = 114 ms; old/young = 3.6). F(1, 46) = 87.4, MSE = 19.383.4, p < .01, η² = .66. The finding of large age differences in global costs could thus be replicated here.

Inspection of Figure 2 provides little evidence that the global selection cost may be a simple effect of accumulated micropractice with the same task (Meiran, 1996). Admittedly, with the limited number of repetitions, it is difficult to rule out the micropractice account completely. However, by the ubiquitous power law of practice (e.g., Newell & Rosenbloom, 1981), the largest practice benefits should be obtained within the first few trials. Instead, micropractice seemed to reach asymptote after as little as two trials with the same mental set. Beyond the second set-repetition contrast, none of the effects associated with the set-repetition contrasts were significant, and the large age difference in global selection costs held even when comparing RTs from the third no-switch repetition with single-task RTs (old, M = 348 ms; young, M = 86 ms; old/young = 4.0). These results thus seem to provide relatively strong evidence against the possibility that age differences in global costs simply reflect age differences in the rate of gradual adaptation to changed task demands.

Local switch costs and response repetitions. Both age groups exhibited local switch costs (i.e., larger switch RTs than no-switch RTs): switch contrast, F(1, 46) = 92.1, MSE = 15.017.8, p < .01. These were somewhat larger for old (M = 177 ms, SD = 126) than for young (M = 101 ms, SD = 65) adults, F(1, 46) = 7.0, MSE = 15.017.8, p < .05, η² = .13. The switch effect was modulated by a highly significant three-way interaction involving age, switch, and the response-repetition factor, F(1, 46) = 22.6, MSE = 2.771.3, p < .01, η² = .33, which could be attributed to much larger response-repetition effects for old adults than for young adults in the case of no-switch transitions (old, M = 116 ms; young, M = 34 ms) and to a reversal of this effect in the case of set changes (old, M = 41 ms; young, M = 5 ms). This age-differential pattern suggests that the moderate age effects in switch costs can be attributed in part to greater facilitation in old adults when responses repeat for no-switch transitions. If one looks at response-change trials only (i.e., when response priming played no role), switch costs were 81 ms for young and 98 ms for old adults, a difference that was not significant, t(46) = 0.62, p > .5.

Finally, it is also interesting to note that age effects in response priming differed between the no-switch task-selection trials (old, M = 116 ms; young, M = 34 ms) on the one hand and the single-task trials on the other (old, M = 21 ms; young, M = 27 ms). Thus, there was no general age-related increase in response priming. Rather, the set-selection context seems to be highly critical for the emergence of the large age difference in response priming. This issue is taken up again in Experiment 2 and in the General Discussion section.

Backward inhibition. The backward inhibition effect is operationalized as the RT difference between inhibition-sequence trials (e.g., color-size-color) and control-sequence trials (e.g., shape-size-color). All trials from set-selection blocks were classified as belonging to either one of these two categories or were discarded from further analysis.

RTs on backward-inhibition trials were, for both old adults (M = 1.164 ms, SD = 256) and young adults (M = 61.3 ms, SD = 111 ms), longer than RTs from control trials (old, M = 1.109 ms, SD = 231 ms; young, M = 598 ms, SD = 115 ms). In an ANOVA with age and the inhibition contrast as factors, both the inhibition contrast, F(1, 46) = 94.6, MSE = 1.214.6, p < .01, η² = .35, and the interaction between the two factors, F(1, 46) = 8.2, MSE = 1.214.6, p < .01, η² = .15, were significant. The inhibition score of 55 ms for old adults and of 15 ms for young adults was significant within each of the age groups: old, t(23) = 4.4, p < .01; young, t(23) = 2.2, p < .05. However, as indicated by the significant interaction, the inhibition effect was larger for old than for young adults. The Age X Inhibition interaction just failed to reach significance when log RTs were analyzed, F(1, 46) = 3.4, MSE = 1.362.9, p = .07, η² = .07. Finally, response priming effects did not modulate the backward inhibition effect in a reliable manner.

![Figure 2](image-url) Old and young adults' mean response times (RTs) separately as a function of the response-repetition factor for set changes; first, second, and third set repetitions; and the single-task condition. Squares = response changes; circles = response repetitions; open symbols = old adults; filled symbols = young adults.
These results replicate the backward inhibition effect reported by Mayr and Keele (2000) with a new set of tasks (although for young adults, the effect was smaller than the one reported originally). However, there was no indication of an age-related decline in terms of inhibition. In absolute terms, the inhibition effect was even larger for older than for younger adults. Thus, the view that reduced backward inhibition may be causally related to age differences in global costs is probably incorrect, and a reappraisal of the functional role of backward inhibition in the context of age differences in the selection between mental sets seems necessary. In this respect, it is interesting to note that there is reason to suspect that backward inhibition is a low-level, automatic process that may be elicited by certain triggering conditions such as competition between a to-be-activated set and an irrelevant set (Mayr & Keele, 2000, Experiment 5; see also Arbuthnott, 1996). Thus, backward inhibition may be not so much a precursor of activating the relevant mental set but instead may be automatically recruited to the degree to which activating the relevant set is difficult. By this view, results are more consistent with age differences in establishing and maintaining the relevant set. More inhibition may be needed in old than in young adults for the adequate set to reach or keep above-threshold activation.

The failure to find a negative age difference in backward inhibition is inconsistent with results supporting the inhibition-deficit hypothesis as proposed by Hasher et al. (1999). What may be the reason for this divergence of results? Mayr and Keele (2000) speculated that backward inhibition is an obligatory process in sequential-selection situations without which a sequential element cannot be replaced by its successor. It is interesting to note in this context that there is another sequential-inhibition phenomenon—namely, spatial inhibition of return—in which old adults show equivalent or even greater inhibition than young adults (e.g., Hartley & Kielley, 1995). Possibly, an age-related inhibitory deficit is more likely to occur when inhibition is not obligatory for successful performance but is just one of several strategies of the cognitive system to deal with interfering information. Specifically, in many concurrent selection situations, it should be possible to deploy early selection processes to keep distracting information out (something that is not possible in sequential selection situations in which the system needs to get rid of a code that already is highly activated “within the system”). One scenario, at this point certainly speculative, is that inhibitory processes are principally intact even in old adults but may be more demanding for the older person’s system. Thus, when alternative selection mechanisms can be used, inhibition is avoided, but when it is the only possible selection process (as possibly in sequential selection situations), it becomes manifest in old and young adults alike.

An alternative scenario is that backward inhibition during sequential selection of mental sets is functionally dissociated from inhibition that is used to keep task-irrelevant information from interfering with task-appropriate settings. In fact, recent results from Oberauer (1999) suggest that disengaging from information in working memory and keeping information from intruding back into working memory may be supported by distinct processes, only the latter of which is sensitive to aging. In any case, the present results, along with those of others (Hartley & Kielley, 1995; Oberauer, 1999), suggest that a closer look at the distinction between concurrent-selection and sequential-selection situations with respect to inhibitory processes may prove informative for the question of whether there is a true decline in inhibitory functions in older age.

Conclusion. The results of this experiment provide clear evidence for the existence of global selection costs and in particular for large age differences therein. Replicating findings by Kray and Lindenberger (2000), we found that very large age differences in global set-selection costs were obtained, whereas age differences in local switch costs were moderate. Significantly, the global selection-cost pattern was found in a situation with low sequencing demands. Thus, at least one possible confound between the single-task condition and the set-selection condition present in Kray and Lindenberger’s (2000) study was ruled out here. Also, the development of RTs across successive same-set repetitions indicates that the difference between set-selection RTs and single-set RTs is probably not simply a function of accumulated micropractice.

One possible source of a global selection deficit, lack of backward inhibition (Mayr & Keele, 2000), could be ruled out as directly relevant for age differences in set-selection costs. Backward inhibition was found for older and younger adults, and if anything, it was larger for older adults. This may suggest that backward inhibition is recruited to compensate difficulties with the successful activation and maintenance of the currently relevant set.

Experiment 2: Boundary Conditions for Age Differences in Set-Selection Costs

In Experiment 1, the finding of large age differences in global set-selection costs reported by Kray and Lindenberger (2000) was replicated under conditions in which sequencing demands could not be made responsible for the deficit. However, the way the cuing paradigm was implemented in Experiment 1 may have been suboptimal. Specifically, one could raise the question of to what degree the amount of time the cue was presented before the stimulus was sufficient (in particular, for old adults) and, if sufficient, was actually used for preparing a new set or maintaining the preceding set. Therefore, in Experiment 2, the cuing procedure was changed in two ways. First, the cue was presented 1,200 ms before the appearance of the stimulus so that twice as much time for preparation was available as in Experiment 1. Also, the cue was presented for 800 ms only and then disappeared. This forced participants to encode the cue during the preparation phase, rather than wait until the stimulus was presented.

Aside from cue-related issues, there are also other factors that may have contributed to set-selection cost in both the study by Kray and Lindenberger (2000) and in Experiment 1. The most important aspect is that the number of relevant S–R rules that had to be maintained for successful response selection varied between single-task blocks and set-selection blocks so that working-memory demands may have differed for the two conditions. Therefore, in Experiment 2, a new control situation was introduced, one that was exactly matched to the set-selection condition, with the only exception being that stimuli were always unambiguous (see also Keele & Rafał, 2000). Thus, participants had to keep all relevant S–R rules active; however, no stimulus-elicited set competition was involved here, and processing of the cue was not relevant to solving the task. This condition is called the unambiguous set-selection condition.

The most important goal of Experiment 2, however, was to try to better characterize age effects in global selection costs by
identifying critical boundary conditions for this effect. A variable that should influence such set-selection costs is the degree to which competing sets can be internally differentiated. For example, when stimuli are ambiguous such that they cue both possible sets, then internal differentiation through a set-updating process may become relevant. However, in this context, it is important to note that some RT costs arise even when processing operations that are triggered in a purely stimulus-driven manner vary across trials. Los (1999) provided evidence that these so-called “mixing costs” reflect low-level priming of relevant operations that accumulates across same-set trials but is missing when operations change. In contrast, the label “global set-selection costs” is reserved for costs associated with the endogenous selection of sets. Therefore, another reason why manipulating stimulus ambiguity is important in the present context is that it allows one to distinguish between bottom-up-driven mixing costs and global selection costs that supposedly reflect demands of endogenous differentiation between sets.

An additional factor aside from stimulus ambiguity that may be critical for set differentiation is the degree of overlap between response specifications across competing mental sets. When selection has to occur between two tasks that are mapped onto the same response options, set differentiation may be particularly difficult. Note that this condition was given both in Experiment 1 and in the Kray and Lindenberger study (2000), where large age differences in set-selection costs were obtained. As already mentioned in the introduction, most other studies in which age differences in selection costs were assessed reported no substantial age difference (e.g., Brinley, 1965; Mayr & Kliegl, 2000a; Saltz et al., 1998). Interestingly, in these studies, either different response specifications were used for each task or the response requirements were highly natural (e.g., speaking the word associated with a particular semantic category, Mayr & Kliegl, 2000a), thus probably eliminating the need to implement a response set at all. Moreover, there is evidence from dual-task situations which suggests that old adults have particular problems with dual-task interference when two tasks overlap on the response end (e.g., Korteling, 1993).

Response-set overlap may be a factor that determines the degree to which sets can be differentiated and thus could be critical for the emergence of set-selection costs. However, a question that follows is what exactly constitutes response-set overlap. For example, the critical degree of overlap may be given when the same response devices need to be used for both tasks (i.e., the same response keys). Another possibility is that not the physical, but the “conceptual,” overlap is critical. For example, if Task A requires making left-right keypress responses with the left hand and Task B requires left-right keypress responses with the right hand, conceptual overlap could be argued because the same spatial layout needs to be used across the two hands. Response-set overlap was therefore manipulated in three levels in this experiment: no overlap, conceptual overlap, and full overlap.

Figure 3 presents the critical conditions used in Experiment 2. As apparent, a set-selection situation with ambiguous stimuli (ambiguous set-selection condition) was compared with a control set-selection condition in which stimuli were unambiguous. (To allow comparisons with Experiment 1, we added a single-task control condition that is not shown in Figure 3). Orthogonal to the within-participant ambiguity factor, the response-set overlap between the two tasks was manipulated across three groups of participants. In the full-overlap group, the same two response keys (and the same hand) were used for both tasks (as in Experiment 1). In the conceptual-overlap group, the two tasks were mapped onto each of the two hands, but the same spatial key arrangement was used for each of the

![Figure 3](image-url)  
*Figure 3.* Design of Experiment 2. Stimuli were either ambiguous or unambiguous (within-subject factor), and response keys could vary in degree of overlap (between-subjects factor). For each level of response overlap, only one of several possible implementations is shown. Note that response keys in the complete overlap condition were either on the left or on the right side in the actual experiment.
two tasks. Finally, in the no-overlap condition, the spatial key arrangement was different for the two tasks.

**Method**

**Participants.** Thirty-six old adults \((M = 70.9\text{ years}, SD = 3.9); 18\) women and 18 men\) and 36 young adults \((M = 20.1, SD = 1.9); 24\) women and 12 men\) participated in this experiment. Young adults were either students at the University of Potsdam or 13th-year students from a nearby high school. Old adults were selected for having participated in higher education. In a multiple-choice vocabulary test \((Lehrl, 1977)\), old adults showed superior performance compared with young adults \(\text{old, } M = 32.7, SD = 1.5; \text{young, } M = 31.4, SD = 2.2, t(70) = 2.75, p < .01.\) In the Digit Symbol Substitution test \((Wechsler, 1964)\), which measures psychomotor speed, we found the usual pattern of young adults outperforming old adults \(\text{old, } M = 49.5, SD = 9.3; \text{young, } M = 64.2, SD = 7.7, t(70) = 7.3, p < .01.\) Participants received a compensation of DM 12 (about $6).

**Tasks and stimuli.** Stimulus presentation occurred on a 17-in. \((43.2\text{ cm})\) Macintosh monitor. Within a white stimulus frame \(\text{(side length = 40 mm)}\), the stimulus object was presented centrally on a black background. The stimulus object was either a line \((10 \times 2 \text{ mm})\) that was oriented vertically or horizontally or a cross made up of a horizontal and a vertical line \(\text{(see Figure 3)}\). The line was cyan, magenta, or white. Horizontal and vertical were the response-relevant values for the form dimension; cyan and magenta were the response-relevant values for the color dimension; the cross and the white color served as neutral values for the two task dimensions. The task cue \(\text{(i.e., form or color)}\) was presented centrally within the stimulus frame \(\text{(but disappeared before the stimulus appeared)}\).

To manipulate response-set overlap, we used the numerical block and the function-key block just left of the numerical block on the standard Macintosh keyboard. Three different principal settings were used, each of which was implemented in different ways to control all possible spatial-response aspects across experimental conditions. Within each age group, participants were randomly assigned to each of the three response-set conditions. In the **full-overlap condition**, responses were made \(a\) with the left hand on the horizontally aligned “delete” key \(\text{(left)}\) and “diagonal-downwards” key \(\text{(right)}\) of the function-key block; \(b\) with the left hand on the vertically aligned “help” key \(\text{(top)}\) and the “delete” key \(\text{(bottom)}\) of the function-key block; \(c\) with the right hand on the horizontally aligned “9” key \(\text{(left)}\) and “z” key \(\text{(right)}\) on the numerical block; or \(d\) with the vertically aligned “a” key \(\text{(top)}\) and “z” key \(\text{(bottom)}\) on the numerical block. For horizontal alignments, the left key was used for horizontal and cyan lines; for vertical alignments, the bottom key was used for horizontal and cyan lines, the top key for vertical and magenta lines. In the **conceptual-overlap condition**, the same set of keys was used but was combined such that the color task was responded to with the left hand and the form task with the right hand, and either the vertical alignment or the horizontal alignment was used on both sides. Finally, in the no-overlap condition, again the same keys were used, but now they were combined such that either the vertical alignment was used on the left side and the horizontal alignment was used on the right side or vice versa. Within the three response-set overlap groups, the four specific implementations were counterbalanced across participants, and each participant worked with one implementation throughout.

**Procedure.** Within each trial, the task cue was presented 200 ms after the response to the preceding stimulus and remained present for 800 ms. Then it disappeared, and 400 ms later, the stimulus object was presented. The stimulus object disappeared together with the response. In case of an incorrect response, the stimulus simply remained on the screen until the correct response was entered.

In total, 18 blocks of 50 trials each were presented, consisting of three identical six-block cycles. Each cycle consisted of two single-task blocks with ambiguous stimuli \(\text{(one block per task)}\), two unambiguous set-selection blocks, and two ambiguous set-selection blocks. The two same-type blocks were always presented together, but the sequence of block types within the six-block cycle was counterbalanced across participants. Whenever the block type changed from the previous block \(\text{(i.e., every two blocks)}\), a 10-trial practice block was inserted that could be repeated on demand. An instruction from the screen informed about the tasks relevant for the upcoming block. The first six-block cycle was used as practice, and only the remaining two six-block cycles were analyzed.

**Results**

Correct RTs after at least one correct trial were retained for further analysis. Within each age group, all RTs larger than 99.5% of that age group’s RT distribution were discarded \(\text{(i.e., old adults, RTs} < 2.022 \text{ ms; young adults, RTs} < 1.095 \text{ ms)}\). Accuracy was generally high, again, with old adults \(M = 98.3\%, SD = 2.1\) being slightly more accurate than young adults \(M = 96.7\%, SD = 2.5\), \(F(1, 66) = 9.2, MSE = 2.268.8, p < .01.\) Interactions between age and any of the experimental factors were far from significant for accuracy. Also, the few non-age-related accuracy effects were all in the same direction as the RT effects. Therefore, further reports on accuracy data are omitted. Unless reported otherwise, all significant, theoretically critical age effects were significant at least at the \(p = .01\) level also for log RTs.

Figure 4 shows RTs for old and young adults and the three different response-set conditions from set-selection trials separately for ambiguous and nonambiguous stimuli and differentiated into switch trials and first, second, and third set-repetition trials \(\text{(see also Appendix B). In addition, single-task RTs are shown. For the main analysis, age was used as one between-subjects contrast, and two between-subjects contrasts were used to analyze differences between response-set conditions. Given that the full-overlap condition is most representative of the condition that in preceding work has produced global selection costs, the first contrast was used to test this condition against the mean of the remaining two conditions. The second contrast tested the conceptual overlap against the no-overlap condition. Stimulus ambiguity was used as a within-subject factor together with three orthogonal contrasts for the different types of local transitions: switch contrast \(\text{(switch trials against remaining trials)}\), first repetition contrast \(\text{(first set repetitions against the mean of the second and third set repetitions)}\), and second repetition contrast \(\text{(second set repetitions against third set repetitions)}\).}

**Global selection costs.** Global selection costs become manifest in the difference between ambiguous versus unambiguous set-selection conditions. As can be seen in Figure 4, such a difference is present throughout, but in particular in old adults \(\text{(young, } M = 23 \text{ ms; old, } M = 88 \text{ ms; old/young} = 3.8\). Accordingly, there was a highly significant ambiguity effect, \(F(1, 66) = 89.6, MSE = 5.139.2, p < .01.\) and a highly significant Age \(\times\) Ambiguity interaction, \(F(1, 66) = 27.9, MSE = 5.139.2, p < .01, \eta^2 = .30.\) Thus, global selection costs and age differences therein were found even though working-memory demands \(\text{(i.e., sequencing demands and number of S-R rules)}\) were held constant. Interestingly, large age effects in global costs were obtained here despite the fact that overall, global costs were much smaller than in Experiment 1. The smaller global costs in this experiment were probably due to the fact that with the longer intertrial and cue-stimulus intervals, more opportunity for preparation was provided here.

On the basis of the assumption that set differentiation is a critical factor determining global costs, it was predicted that these
costs should increase as a function of response-set overlap. As is apparent from Figures 4 and 5, age differences in global set-selection costs were very large for the full-overlap condition (old/young = 6.9) but about equally large for the other two conditions (for both conditions, old/young = 2.4). Also, it should be noted that this increase in costs was constrained to the ambiguous-stimulus condition. Accordingly, the interaction among age and the first response-set contrast and the ambiguity factor was highly significant, $F(1, 66) = 8.9, MSE = 5,139.2, p < .01$, $\eta^2 = .12$, whereas the corresponding interaction for the second contrast was not significant, $F(1, 66) = 0, MSE = 5,139.2, p > .9, \eta^2 = 0$. Thus, for age differences in global selection costs to emerge, both full response-set overlap and stimulus ambiguity must be present, whereas degree of conceptual overlap plays no role.

Analysis of set-repetition effects revealed a micropractice pattern up to the second set repetition, $F(1, 66) = 8.69, MSE = 581.0, p < .01$, but not for the third set repetition. Higher order interactions emerged in association with the second and third set repetitions and reflect unexpected effects (old adults’ RTs in the no-overlap second-repetition RTs and in the conceptual-overlap third repetition were unexpectedly high). There is no obvious explanation for these effects, but they disallow firm conclusions about the development of global set-selection costs in the absence of full response-set overlap. However, as can be seen in Figure 4, the global selection cost in the ambiguous full-overlap condition showed no tendency to converge toward the level of RTs from the corresponding unambiguous selection condition. Thus, again, there is little evidence that would suggest age differences in micropractice as a possible reason for age differences in global costs.

Global selection costs were obtained for the contrast between ambiguous and unambiguous stimuli. Thus, the number of relevant S–R rules does not seem to be a critical factor for the emergence of such costs. However, an additional question is whether or not the mere fact that two different tasks are relevant produces a global cost when compared with the single-task condition. As can be seen in Figure 4, young adults’ RTs from the condition with unambiguous stimuli converged toward the single-task RT. However, for old adults, there seemed to be a remaining difference. As a test of this difference, the third set repetition from the condition with unambiguous stimuli was contrasted with the single-task condition. Old adults produced significantly longer RTs in the unambiguous set-selection condition than in the single-task condition ($M = 32, SD = 49$), whereas for young adults, the difference was very small ($M = 5 ms, SD = 27$). $F(1, 66) = 7.9, MSE = 1,556.1, p < .01, \eta^2 = .07$. It should be noted, however, that at least in part, this effect was due to the unexpectedly long third-repetition RTs of old adults in the no-overlap condition. When this condition is eliminated, the remaining cost is 18 ms for old adults and 4 ms for young adults.

Figure 4. Old and young adults’ mean response times (RTs) as a function of the stimulus-ambiguity and the response-set overlap factor for set changes; first, second, and third set repetitions; and the single-task condition. Circles = ambiguous stimuli; squares = unambiguous stimuli; open symbols = old adults; filled symbols = young adults.

Figure 5. Global set-selection costs (i.e., response time difference between ambiguous and unambiguous selection response times) as a function of age and response-set overlap. Error bars reflect within-subject 95% confidence intervals (Loftus & Masson, 1994) for the Stimulus Ambiguity $\times$ First Response-Set Overlap contrast computed separately for old and young adults.
young adults and just fails to reach significance, $F(1, 44) = 3.3, \text{MSE} = 520.3, p > .05$, $\eta^2 = .07$. In other words, there may be a small global-cost component in old adults that cannot be attributed to the stimulus-ambiguity factor (i.e., mixing costs; Los, 1999). The important point, however, is that this ambiguity-unrelated component is very small compared with the ambiguity-related global-cost component and that it was not modulated through response-set overlap. Thus, a clear dissociation between bottom-up-driven mixing costs (Los, 1999) and global set-selection costs was achieved here.

**Local switch costs and response-repetition effects.** The switch contrast revealed switch effects for both age groups, $F(1, 66) = 113.5, \text{MSE} = 2,225.7, p < .01$, that were larger for old adults than for young adults, $F(1, 66) = 21.7, \text{MSE} = 2,225.7, p < .01$, $\eta^2 = .25$ (young, $M = 27.2$ ms; old, $M = 70$ ms; old/young = 2.5). It is interesting to note that switch costs were only moderately larger for ambiguous than for unambiguous stimuli, $F(1, 66) = 4.2, \text{MSE} = 859.8, p < .05, \eta^2 = .05$. This difference seemed to be due to a trend in the direction of larger switch costs for ambiguous stimuli in old adults, $F(1, 66) = 3.3, \text{MSE} = 1,098.1, p > .07$. Finally, unlike global selection costs, switch costs were not affected by response-set overlap, $F(1, 66) = .39, \text{MSE} = 659.8, p < .05$. Thus, local switch costs behaved in a very different way than global costs. They seemed to be affected only moderately, by stimulus ambiguity and by response-set overlap. In contrast, global costs were substantially affected by both factors, at least in old adults.

In Experiment 1, the response-repetition factor was found to be critical in modulating age differences in local switch costs. In the present experiment, this factor cannot be analyzed for the full design because response repetitions were not defined in the case of set transitions for the no-overlap condition and also because the number of observations was too small for third set-repetition trials when including this factor. Therefore, only the full-overlap and the conceptual-overlap conditions were analyzed, and RTs were pooled across the three different set-repetition categories. The relevant data are shown in Figure 6. For young adults, response repetitions seemed to play no role. Accordingly, when we analyzed young adults only, no significant effects involving the response-repetition factor were obtained (all $F$s < .5). However, old adults showed a substantial repetition effect for ambiguous-condition no-switch trials. Accordingly, in the full ANOVA, a significant Age × Switch × Response Repetition interaction was found, $F(1, 46) = 11.02, \text{MSE} = 2,483.2, p < .01, \eta^2 = .21$, that was further modulated by the stimulus-ambiguity factor, $F(1, 46) = 5.6, \text{MSE} = 1,771.1, p < .05, \eta^2 = .11$. To decompose this interaction, we analyzed ambiguous and unambiguous stimulus conditions separately. The Age × Switch × Response Repetition interaction was obtained for ambiguous stimuli, $F(1, 46) = 13.8, \text{MSE} = 1,275.6, p < .01, \eta^2 = .24$, but not for unambiguous stimuli, $F(1, 46) = 1.3, \text{MSE} = 835.6, p > .25, \eta^2 = .02$. Response-set overlap did not enter into interactions with the repetition-priming effect. Thus, one important new result from Experiment 1—namely, the much larger response-priming effect for old adults in set-selection situations—could be fully replicated here. Further, stimulus ambiguity was determined as a critical boundary condition for this age-specific effect.

Finally, to provide a complete picture, data from the single-task condition are also presented in Figure 6. As is apparent, for both age groups, response-priming effects seemed somewhat stronger in the single-task condition than in no-switch trials of the unambiguous set-selection condition (which is the most appropriate comparison condition for the single-task condition). Accordingly, in an ANOVA comparing these two conditions, the Condition × Response Repetition interaction was significant, $F(1, 46) = 4.4, \text{MSE} = 429.9, p < .05$, whereas none of the age-specific interactions were significant.

In light of the pattern of response-repetition effects, it is again necessary to reappraise the local switch-cost results. A quite substantial age difference in switch costs had been reported above and also a general increase of switch costs with stimulus ambiguity. However, when one looks at the response-change trials, it becomes clear that switch costs were highly similar for ambiguous and unambiguous trials and that age effects were only moderate (see Figure 4). It is only for response repetitions that large switch costs for old adults emerged, which can be attributed largely to greater facilitation in the case of response repetition rather than to actual switch costs (old, $M = 54, SD = 72$; young, $M = 28, SD = 30$), $F(1, 46) = 36.9, \text{MSE} = 1,782.9, p < .01, \eta^2 = .46$. In contrast, the analysis of switch costs for response-change trials revealed a comparatively small age effect (old, $M = 103, SD = 52$; young, $M = 29, SD = 32$), $F(1, 46) = 2.3, \text{MSE} = 2,765.2, p > .1, \eta^2 = .09$.

**Conclusion.** The main result from Experiment 1, the large age difference in global set-selection costs, was fully replicated here in a situation in which it can be attributed neither to sequencing demands nor to the number of S–R rules. Further, age differences in global selection costs were very large only when two boundary
conditions were met: stimulus ambiguity and full response-set overlap. This is the situation in which internal differentiation between mental sets should be most difficult. Thus, the combined effect of stimulus ambiguity and response-set overlap suggests that age differences in global set-selection costs can be attributed to an age-related problem in a set-updating process that has the role of “cleaning up” internal control settings and that becomes necessary in the face of ambiguity in the task environment. Finally, the large age difference in response priming found in Experiment 1 was replicated here but was limited to the ambiguous set-selection condition. Thus, set-specific processes may be contributing to this effect in a critical way.

General Discussion

An important general result of this work is the finding that even when people have complete knowledge about the type of action to perform in the immediate future, they have problems implementing this knowledge in an optimal manner when more than one action rule may be relevant in principle. This was expressed in an increase of RTs during task-switching blocks even when no actual switch between tasks occurred and sufficient time to make use of the cue was provided. The critical finding from an aging perspective is that at least under certain conditions, this knowledge-implementation gap increased quite dramatically in old age. In contrast, age differences in RT costs at actual task-switch points were much more moderate. This result provides a conceptual replication of a set of findings reported by Kray and Lindenberger (2000) under conditions that allowed ruling out interpretations of global set-selection costs in terms of working-memory demands. In addition, both in old and young adults, inhibition on the level of task sets could be demonstrated, thus ruling out the possibility that an inhibitory deficit is responsible for the age difference in global selection costs. Finally, and most important, large age differences in global costs were constrained to a situation in which stimuli were ambiguous and response specifications overlapped for the relevant tasks. Thus, only when neither the stimulus information nor the response information helps to keep the different sets apart do older adults’ most severe problems seem to arise. Presumably, these demands on internal differentiation of sets force old adults into a processing mode that is characterized by a large engagement in costly set-updating operations. In the remainder of the General Discussion section, the role of response overlap and response repetitions, the relationship between global and local costs, and the relevance of the current results for the question of age differences in executive control are discussed.

Role of Response-Set Overlap

Together with stimulus ambiguity, response-set overlap was found to be a critical boundary condition for the finding of large set-selection costs in old adults. The interpretation of this result offered here is that response specifications are one critical component of task sets and that task sets that share this component should be difficult to “keep apart.” For example, one way to think about this is that using a response specification in one task may act as a retrieval cue for other tasks, of which this specification is a part.

Interestingly, the examination of response-set overlap may also bring order into some of the inconsistencies in the literature on age differences in task-switching costs. In studies in which no age difference in global selection costs was found (e.g., Brinley, 1965; Mayr & Kliegl, 2000a; Salhouse et al., 1998), either different response sets were used for different tasks or responding occurred in a very natural way so that an active response set was not required. In contrast, large age differences in global selection costs were found when there was overlap in response sets (e.g., the present experiments; Korteling, 1993; Kray & Lindenberger, 2000; Mayr & Liebscher, in press; Meiran, Gotler, & Perlman, in press). It is interesting to note that a related finding has also been reported with the Stroop task (Li & Bosman, 1996). Age differences in Stroop interference were found to be larger for overlapping, but not for nonoverlapping, response sets.

What exactly constitutes response-set overlap? To unpack this construct, we made a distinction between conceptual and full overlap. Conceptual overlap (i.e., that the same left-right response codes were used for each of the two response sets) was not sufficient to produce large age differences in general set-selection costs. Only full overlap (i.e., when the same two response keys were used for both tasks) produced the pattern of large age differences. However, the question remains as to what exactly constitutes full response-set overlap. The current design leaves at least two possibilities. In the full-overlap condition, tasks shared both effectors (i.e., the same fingers were used for responding) and the goal locations for responses, whereas in the two different non-overlap conditions, neither of these aspects was shared across response sets. Evidence from work on motor programs suggests that planning of actions does not occur through specification of particular effectors but rather of effector-independent “goal states” (e.g., Keele, Cohen, & Ivry, 1990). From such a view, one would expect that it is the shared goal location that counts and not the shared effectors. Further experiments in which the effector component and the goal-location component are deconfounded will have to be conducted before any definite conclusion on this important issue can be offered.

Response Priming

A surprising result was that response-priming effects in the context of ambiguous set-selection conditions were much larger in old adults than in young adults. However, there may also be a rather straightforward explanation of this result, namely the so-called shortcut account (e.g., Pushler & Baylis, 1991; Quinlan, 1999). On the basis of this account, response-priming effects reflect a familiarity-based repetition of the just-executed action, thus “shortcutting” the otherwise necessary selection process. Of course, the effect of such a shortcut should be larger the greater the relative cost associated with the actual selection process is. Given that old adults’ RTs were larger in the ambiguous-selection condition than in the unambiguous-selection condition, it may not be too surprising that the response-priming effect also becomes much larger in the former than in the latter. Although this seems to offer a simple account of the pattern of results, there may be some doubts as to whether it is fully satisfactory. It is interesting to note that within age groups, there was no general pattern of larger repetition priming going along with larger RTs as would be expected if response priming was simply a function of the amount of
processing that could be bypassed through the repetition. In fact, repetition priming in the fastest condition, namely the single-task condition, was actually significantly greater than in unambiguous-selection conditions.

What then may have contributed to the old adults' large response priming in the ambiguous set-selection condition? One interesting possibility is that the magnitude of the response-priming effect in old adults is another indication of the proposed older adults' large involvement in set-selection processes. Specifically, if appearance of the stimulus elicits a set-updating operation in old adults, this may allow the binding of the item-specific S-R configuration to the simultaneously activated mental set. Reactivating the "entire package" on the following trial would then lead to the large priming effect, possibly reflecting not only facilitated response selection but also facilitated set selection. In contrast, in young adults, stimulus presentation probably occurs in the face of a well-established mental set. As a consequence, set updating can be avoided at the time of S-R processing, which in turn gives bindings between set-level representations and S-R constellations no opportunity to emerge.

Local Switch Costs Versus Global Selection Costs

The main variable in task-switching research is the local cost that arises at actual switch points. However, the repeated finding that global set-selection costs are sensitive to interesting experimental manipulations (see present experiments), particular pathologies (Keele & Rafal, 2000), and adult age (Kray & Lindenberger, 2000) suggests that these costs may be at least as important as an indicator of executive control as the local costs. It is interesting to note that the finding of selective deficits in global costs, both with respect to frontal pathology and aging, suggests a functional dissociation between the two indicators of set-level selection. Such a dissociation is also indicated by the finding of two distinct psychometric factors for the two types of costs that was reported in Kray and Lindenberger (2000). Moreover, the current Experiment 2 indicates that age differences in global costs were very sensitive to stimulus ambiguity and response overlap. In contrast, local costs were virtually unaffected by these variables (at least when taking into account the effect of response repetitions). The insensitivity of local costs to variations of S-R ambiguity is a particularly provocative result because Allport et al. (1994) interpreted both residual switch costs and global costs as proactive interference from the competing task set elicited by the currently irrelevant stimulus dimension. However, this common explanation for both phenomena can only account for switch costs in ambiguous situations and therefore provides no account of the general pattern of results in Experiment 2.

The fact that local costs emerged even in the absence of stimulus ambiguity or response-set overlap may suggest that they were not directly linked to endogenous-selection processes. Instead, they can probably be attributed to the effect of stimulus-driven positive priming of task-specific procedures in the case of set repetitions and to the absence of such effects in the case of set changes (e.g., Los, 1999). Of course, this does not imply that the same is true for all results concerning residual switch costs. The fact that switch costs were relatively small in Experiment 2 may have been related to the fact that the situation used encouraged active preparation (by short presentation of the task cue within a long preparatory inter-}

val). This procedural detail may have eliminated much of the ambiguity-related component that at least some authors have found to be present in residual switch costs (e.g., Rogers & Monsell, 1995). However, it also needs to be noted that in past work, stimulus ambiguity and response overlap have typically not been examined systematically (for an exception, see Meiran, 2000b), so the contribution of lower-level priming effects that occur independently of top-down control is not known. The present results suggest that more attention should be given to such nonexecutive factors contributing to what may look like executive effects in task-switching costs.

A final issue concerns the interpretation of local costs in the presence of global costs (and in particular in the case of group differences in global costs). One way to think about the hypothesis of a larger reliance on set updating in old than in young adults could be that old adults need to select the relevant mental set on switch and on no-switch trials, whereas young adults need to do this only on switch trials. In this case, local switch costs would reflect the duration of switching operation in young adults, but not in old adults, rendering an age comparison misleading. Whether or not this interpretation is correct, it suggests that caution is in order when interpreting the absence of group differences in local costs as the absence of a switching or a set-selection deficit (e.g., Keele & Rafal, 2000; Kray & Lindenberger, 2000). At least in some situations, global costs may actually be a more fundamental and less ambiguous indicator of executive control demands in set-selection situations than local costs.

Global Set-Selection Costs and Age Differences in Executive Control

The suggestion that an updating process that "cleans up" internal control settings is responsible for global costs provides a reasonable first-pass account of the existing data on set-selection costs and age differences therein. However, a number of questions remain.

A very important issue is the nature of the triggering condition for the proposed updating operation. For example, set updating may be elicited as a purely stimulus-driven process. Specifically, the actual ambiguity at the moment of stimulus presentation and response selection may produce set interference that then has to be resolved by the updating operation. Alternatively, the mere possibility of ambiguity may elicit a mode of processing in which updating at the moment of stimulus presentation or response selection occurs irrespective of the actual ambiguity. Specifically, such a processing mode could be characterized by the fact that certain triggering conditions (e.g., stimulus appearance) are specified for set-updating operations.

A definite answer regarding this question is currently not possible. However, already the existing data allow one to rule out a purely stimulus-driven process. For example, in Experiment 2, single-task blocks with ambiguous stimuli were intermixed with set-selection blocks. If the updating operation is purely stimulus driven, then large age differences should be expected even in these single-task blocks. Thus, at the very least, an interaction between an "updating" control setting that can be implemented in a relatively flexible manner (i.e., from block to block) and stimulus-driven set competition needs to be taken into account. A design that would allow us to examine relative contributions of stimulus-
driven processes versus contextual processes is one in which ambiguous and unambiguous stimuli are intermixed within a block and are also compared with pure, unambiguous set-selection blocks (as in Experiment 2). Recent experiments with such a design in young adults revealed that about half of the global costs become manifest in the comparison between the mixed and the blocked unambiguous-stimulus condition. Thus, global costs have both a stimulus-driven component and a contextual component (Mayr & Kliegl, 2001). Which of these two components is responsible for the large age effects in global costs is an important question in our ongoing work.

A second important question concerns the nature of the proposed updating operation. Recently, Mayr and Kliegl (2000b) have argued that operating in set-selection conditions can be understood best as a problem of navigating a working-memory focus (limited to one of several competing mental sets) through a long-term memory (LTM) retrieval structure that connects possible mental sets to a common context node. Thus, switching to a new task but also updating the current mental set involves a controlled LTM retrieval process. In contrast, operating in single-task situations is so efficient because it requires no controlled LTM retrieval at all; selection of action simply occurs on the basis of the set currently loaded into working memory.

A critical point to note in this context is that LTM retrieval is a relatively costly process. Specifically, controlled retrieval needs time during which other “central processes” (e.g., Carrier & Pashler, 1995) and processing of external stimuli are delayed (Craik, Govoni, Naveh-Benjamin, & Anderson, 1996). In addition, in the presence of interfering stimulus information, retrieval may be particularly slowed in old adults (West, 1999a). In set-selection situations, the executive control system should therefore be faced with an interesting optimization problem. On the one hand, frequency of costly updating operations should be minimized to allow fluent within-set selection. On the other hand, occasional updates may be necessary in order to maintain reliable settings. It is at this optimization problem that old adults may function under a different regime than young adults. In set-selection situations, old adults may generally operate under an updating control mode, whereas young adults may be more flexible in moving from an updating mode (e.g., at switch trials or during cue encoding) to a within-set selection mode of control (e.g., at no-switch trials or during stimulus encoding). An important question in this context is whether such differences in executive-control regimes are enforced by a less reliable representation of sets in old age. The alternative possibility is that these differences are due to strategic adaptations (and possibly overadaptations) to age-related decrements that, however, could be changed through adequate interventions.

A final issue is to what degree the results presented here are relevant for the more general issue of age deficits in executive control. It is interesting to note that there are a number of recent results that seem to suggest that old adults may have particular problems with representing higher level control settings. For example, West (1999b) presented results suggesting that old adults have more frequent lapses of intentions than young adults. A greater reliance on updating operations would be a natural consequence of less reliable representations of currently relevant action plans. A further important hint comes from recent work on source monitoring. Henkel, Johnson, and De Leonards (1998) suggested that old adults have particular difficulties with creating and retrieving events that share features with competing events. Specifically, old adults seem to have a problem when event features have to be integrated to create distinct representations. Interestingly, when mental sets share common elements (e.g., response sets), unique bindings of elements should be critical for set differentiation. Thus, the hypothesis of a binding deficit is consistent with the finding that old adults have the largest set-selection costs when the difficulty of creating distinct representations of mental sets should be largest (i.e., when stimuli are ambiguous and response sets overlap).

To conclude, global set-selection costs provide a handle onto executive control phenomena that occur on a more molar time scale than is assessed via trial-by-trial switching effects. It is yet to be determined exactly how old and young adults differ in terms of such molar control modes. However, that such differences exist is clearly demonstrated by the fact that age effects in global set-selection costs were established as a replicable phenomenon in this article. Hints about possible mechanisms are provided by the fact that age effects in global costs were associated with demands on differentiating and updating internal control settings. Finally, the finding that response-set overlap is a critical factor in this respect may bring order into some of the inconsistencies in the literature on age differences in task switching.

References


Mean Response Times (in Milliseconds) as a Function of Age, Response Repetitions Versus Changes, and Number of Task Repetitions in Experiment 1

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### Appendix B

#### Mean Response Times (in Milliseconds) as a Function of Age, Stimulus Ambiguity, Response Overlap, and Number of Task Repetitions in Experiment 2

<table>
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<tr>
<th>Response overlap</th>
<th>Stimulus ambiguity</th>
<th>No. of task repetitions</th>
<th>Single task</th>
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