Examining Age-Related Differences in Auditory Attention Control Using a Task-Switching Procedure

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Objectives. Using a novel task-switching variant of dichotic selective listening, we examined age-related differences in the ability to intentionally switch auditory attention between 2 speakers defined by their sex.

Method. In our task, young (M = 23.2 years) and older adults (M = 66.6 years) performed a numerical size categorization on spoken number words. The task-relevant speaker was indicated by a cue prior to auditory stimulus onset. The cuing interval was either short or long and varied randomly trial by trial.

Results. We found clear performance costs with instructed attention switches. These auditory attention switch costs decreased with prolonged cue–stimulus interval. Older adults were generally much slower (but not more error prone) than young adults, but switching-related effects did not differ across age groups.

Discussion. These data suggest that the ability to intentionally switch auditory attention in a selective listening task is not compromised in healthy aging. We discuss the role of modality-specific factors in age-related differences.

Key Words: Auditory selective attention—Cognitive aging—Dichotic listening—Task switching.

An important research question in cognitive aging is whether older adults perform worse in task switching compared with young adults (see Kramer & Madden, 2008, for a review). The task-switching paradigm has become a major research tool to examine cognitive and attentional control. Specifically, the aim of this study was whether there are age-related differences in auditory task switching. In task-switching experiments, participants are instructed to switch between different tasks. Switching between tasks on a trial-by-trial basis typically leads to performance costs, so-called switch costs. Switch costs can be found in both reaction time (RT) and error rates by comparing performance on switch trials with performance on repetition trials (see Kiesel et al., 2010; Vandierendonck, Liefooghe, & Verbruggen, 2010, for reviews).

Many studies reveal increased performance costs in task switching in older adults (Kray, Eber, & Karbach, 2008; Kray & Lindenberger, 2000; Lawo, Philipp, Schuch, & Koch, 2012; Mayr, 2001; Meiran, Gotler, & Perlman, 2001; Salthouse, Fristoe, McGuthry, & Hambrick, 1998), but these age-related differences are still unclear to some extent. In a recent meta-analysis, Wasylyshyn, Verhaeghen, and Sliwinski (2011) took general slowing into account in their meta-analysis of task-switching effects in young and older adults. Even though some studies found age-related differences in switch costs, the meta-analysis by Wasylyshyn and colleagues (2011) showed that these costs were generally similar for both age groups, indicating that older adults were as efficient as young adults in switching between tasks.

Note that almost all of the existing task-switching studies have used visual tasks, and little is known about task switching in auditory tasks. To our knowledge, there is only one study that examined age-related differences in switch costs in the auditory modality. Tun and Lachman (2008) conducted a task-switching study in which participants performed speeded auditory tasks by telephone. Participants switched between two response mappings (i.e., S–R mapping reversal), but the same stimulus selection rules were used throughout. Tun and Lachman (2008) found larger switch costs for older compared with young adults. Notably, this is the only task-switching study requiring auditory selective attention. On the background of the meta-analysis by Wasylyshyn and colleagues (2011), who found no age-related differences in task switching using visual tasks, it is an important question whether the age-related differences found by Tun and Lachman (2008) represent a general phenomenon. Therefore, the question arises whether age-related task-switching deficits are to be expected in the auditory modality.

Our study was aimed at reassessing this finding with a different auditory task-switching variant. To examine whether there are age-related differences in auditory task switching, we used a paradigm recently introduced by Koch, Lawo, Fels, and Vorländer (2011). This paradigm combined the task-switching paradigm and the methodology of dichotic listening. In dichotic listening, participants are required to attend to information presented to one ear while ignoring information presented to the other ear (Broadbent, 1958; Cherry, 1953). Specifically, in the present paradigm, participants had to categorize one of two dichotically presented number words according to numerical size as smaller or larger than 5. In each trial, one female and one
male speaker always spoke these number words, and the participant had to respond either to the female or male speaker, as indicated by a visual task cue.

In this paradigm, preparation for an attention switch with respect to speaker sex can be examined by manipulating the time between the task cue and the stimulus (cue–stimulus interval [CSI]). In their study, Koch and colleagues (2011) observed auditory attention switch costs and showed that these costs decreased with prolonged CSI. This preparatory reduction of switch costs is a typical empirical finding (Kiesel et al., 2010) and has been taken as an important marker of cognitive control (Meiran, 1996).

Previous aging studies showed that this preparatory reduction of switch costs is not impaired in older adults (Hartley, Kieley, & Slabach, 1990; Hsieh & Wu, 2010; Kramer, Hahn, & Gopher, 1999; Meiran et al., 2001), at least in situations comprising only two different tasks (see Lawo et al., 2012, for a discussion). Note though that Tun and Lachman’s (2008) study, which is the only study using the task-switching procedure with auditory tasks, did not examine preparation effects. In this study, we examined preparation effects on auditory switch costs in young and older adults.

Note that our auditory task-switching paradigm differs from traditional studies on dichotic listening (e.g., Broadbent, 1958; Cherry, 1953; see Pashler, 1998, for a review), which did not focus on switching of attention. Even though attention switches occurred spontaneously (involuntarily), these switches were not instructed (see Lachter, Forster, & Ruthruff, 2004; Rivenez, Guillaume, Bourgeon, & Darwin, 2008; Shinn-Cunningham, 2008, for a discussion). In contrast, in our study, we examined explicitly cued attention switches.

The present paradigm additionally allowed us to explore the role of attentional control in processing of task-relevant information in auditory task switching. In each trial, the two number words could either be congruent (both number words smaller or both larger than 5) and therefore call for the same response, or they could be incongruent (one number word smaller and one larger than 5) and therefore call for different responses. Typically, participants respond faster in congruent trials than in incongruent trials (“congruency effect,” see Kiesel et al., 2010, for a review). Notably, Meiran and colleagues (2001) used task switching with two visual tasks and found increased congruency effects in older age, suggesting less efficient attentional control in older adults. Because these authors used visual tasks, it seems important to examine whether this finding generalizes to auditory tasks.

To summarize, this study examined the ability of young and older adults to intentionally switch auditory attention and the ability to prepare for an upcoming attention switch by manipulating the CSI using a selective listening paradigm. Specifically, we assessed switch costs, congruency effects, and their interaction with preparation effects to examine whether there are age-related performance effects in instructed switching of auditory selective attention.

**Method**

**Participants**

Forty German-speaking participants were tested. Twenty young participants (10 women) in the age range of 20–28 years (\( M = 23.2, \ SD = 2.4 \)) and 20 older participants (10 women) in the age range of 59–78 (\( M = 66.6, \ SD = 4.7 \)) took part and received 6 euros. Participants were recruited through the participant pool at the Institute of Psychology at the RWTH Aachen University. All participants had a general qualification for university entrance, and the age groups were matched in terms of school education level.

All participants were in good health and reported no presence of hearing problems. To ensure that there were no elderly participants with mild cognitive impairment (MCI) or with dementia in the early stages of the disease, we used the computer-based version of the screening test DemTect (Kalbe et al., 2004; Kessler, Calabrese, Kalbe, & Berger, 2000). The transformed total score (maximum 18) of the DemTect is independent of age and education (Kalbe et al., 2004). Test scores from 9 to 12 points suggest an MCI and 8 points or below a dementia. The screening test did not reveal conspicuous values and generally showed comparable scores for older and young adults (\( M = 17.4, \ SD = 1.4 \), for older adults, and \( M = 17.9, \ SD = 0.2 \), for young adults). We did not include elderly participants with self-reported hypertension, cardiac arrhythmia, or diabetes.

**Stimuli and Task**

The acoustic stimuli were the spoken number words 1–9 (without 5), presented via headphones (Speed Link, Full Metal Headset, SL8755). Three different female speakers and three different male speakers were recorded in an anechoic chamber at the Institute of Technical Acoustics of RWTH Aachen University. A subjective loudness calibration was carried out for each individual number word and for all different speakers. The procedure of DIN 45631/A1, a German National Standard, was used for calculating loudness. Furthermore, the duration for all different speakers was adjusted across the set of eight number words to be subjectively the same. A time-stretching algorithm was used to shorten the long samples while the pitch was maintained.

The task was to categorize the relevant digit as smaller or larger than 5. The sex of the relevant speaker was indicated by a visual color cue (an asterisk with approximately 3 cm in diameter) presented prior to stimulus onset. The cue was presented at the center of a black screen (17-in. monitor) in either orange or blue color. The colors were easily discriminable and indicated the sex (female vs. male) of the task-relevant speaker trial by trial. The cue-to-sex mapping was counterbalanced across participants. If the task-relevant stimulus was smaller than 5 the participants had to press the left response key with the left index finger, if the task-relevant stimulus was larger than 5 the right response key with the right index finger (Alt & AltGr keys, i.e., left and right of the space
key, respectively). The assignment to the categories (<5 and >5) was held constant according to the mental number line.

**Procedure**

Before the experiment started, the participants completed the dementia-screening test DemTect from Kalbe and colleagues (2004) which included a word list, a number transcoding task, a semantic verbal fluency task (“supermarket”), digit span reverse, and delayed recall of the word list. The DemTect took about 8–10 min. The experiment was run in a single session with one participant at a time and took about 30 min. The instructions for the experiment appeared on the screen at the beginning of the experiment and emphasized speed as well as accuracy.

In each trial, first the visual task cue was presented. After a CSI of either 100 or 1,000 ms, the two acoustic stimuli were simultaneously presented via headphones. The visual cue remained on the screen until participants responded to the acoustic stimuli. The interval between response and next cue (RCI) was varied inversely to keep the overall response–stimulus interval constant (i.e., 1,100 ms). In case of an error, a visual feedback (“Fehler!”, German for “error”) was displayed for 500 ms, delaying the onset of the next cue.

The sex of the relevant speaker, the mapping of sex to ear (left vs. right), identity of speaker within each sex, and the identity of the relevant and irrelevant stimuli varied randomly from trial to trial. The two acoustic stimuli presented to the left and right ear were always different in each individual trial. Repetitions and switches occurred equally frequently.

There were 4 blocks of 144 trials each, separated by short breaks. A practice block of 24 trials to get familiar with the tasks and stimuli preceded the experimental blocks. During the practice block, the experimenter remained in the room to answer questions if necessary.

**Design**

The independent variables were auditory attention shift (switch vs. repetition), CSI (100 ms vs. 1,000 ms), and congruency (congruent vs. incongruent) as within-participant variables and age group (young adults vs. older adults) as between-participant variable. The dependent variables were RT and error rates.

**Results**

The practice block (24 trials) and the first trial in each block (“warm-up”) were excluded from the analyses. Data from one participant (an older woman) were also excluded because poor overall performance throughout the experiment (mean error rate exceeding 27%) suggested that the task was not understood correctly. In the RT analysis, only correct trials that were preceded by at least one correct trial were included. As outliers, we excluded (from otherwise correct trials) for each individual participant RTs exceeding 4.5 SDs from the mean (0.6% for the young adults and 0.4% for the older adults).

We first report the analysis of variance (ANOVA) of the RT data, followed by the analysis of the error rates. RTs and error rates were submitted to separate ANOVAs using auditory attention shift, CSI, congruency as independent within-participant variables, and age group as independent between-participant variable. Mean RT as a function of auditory attention shift, CSI, congruency, and age group is shown in Figure 1.

For the RT analysis, the main effect of age group was significant, $F(1, 37) = 15.0, MSE = 410,625, p < .001$,
\( \eta^2_p = .28 \), indicating generally higher RT in older adults than in young adults (1,411 vs. 1,130 ms). The main effect of auditory attention shift was significant, \( F(1, 37) = 91.1, MSE = 16,995, p < .001, \eta^2_p = .71 \), indicating higher RT in switches than in repetitions (1,341 vs. 1,200 ms) and thus switch costs of 141 ms. The interaction of auditory attention shift with age group was not significant, \( F < 1 \), indicating that the switch costs for older and young adults were numerically very similar (156 vs. 126 ms); moreover, given the overall higher RT level of older adults, this represents almost identical proportional switch costs (i.e., relative to task-repetition RT) of 11.7\% vs. 11.8\%, \( F < 1 \). The effect of CSI was significant, \( F(1, 37) = 29.2, MSE = 14,735, p < .001, \eta^2_p = .44 \), indicating that RT was higher with short CSI than with long CSI (1,308 vs. 1,233 ms) and thus demonstrating a substantial preparation benefit (75 ms). CSI did not interact with age group, \( F(1, 37) = 1.6, MSE = 14,735, p > .05, \eta^2_p = .04 \). The effect of congruency was at significance threshold, \( F(1, 37) = 4.1, MSE = 9,682, p = .05, \eta^2_p = .10 \). The interaction of congruency with age group was not significant, \( F(1, 37) = 1.8, MSE = 9,682, p > .05, \eta^2_p = .05 \).

The interaction of auditory attention shift and CSI was significant, \( F(1, 37) = 40.9, MSE = 7,193, p < .001, \eta^2_p = .53 \), indicating smaller switch costs for long CSI than for short CSI (79 vs. 203 ms) and thus a preparatory reduction of switch costs. The interaction of auditory attention shift and congruency was significant, too, \( F(1, 37) = 4.1, MSE = 9,682, p = .05, \eta^2_p = .19 \), indicating unexpectedly, larger switch costs for congruent trials than for incongruent trials (163 vs. 119 ms). The congruency effect did not interact with CSI, \( F < 1 \), but the three-way interaction with auditory attention shift, CSI, and congruency was significant, \( F(1, 37) = 9.3, MSE = 2,437, p < .05, \eta^2_p = .20 \), indicating a larger reduction of shift costs as a function of short CSI on congruent trials than in incongruent trials (156 vs. 88 ms). The three-way interactions with age group and the four-way interaction were not significant, \( F < 1 \).

Note that, apart from the main effect of age group, there was no single significant interaction in the RT data that included the age variable. In addition to using mean RTs, we also conducted an analysis with log-transformed RTs, which are less susceptible to differences in baseline RT that can be expected when comparing performance of older and young adults (Kray & Lindenberger, 2000; Mayr, 2001; Ratcliff, 1993), but there were still no significant interactions with age group.

Error rates were also submitted to an ANOVA using auditory attention shift, CSI, congruency, and age group as independent variables. Mean error rates as a function of auditory attention shift, CSI, congruency, and age group are shown in Figure 2.

For the error rates, the main effect of age group was not significant, \( F < 1 \). The main effect of auditory attention shift was significant, \( F(1, 37) = 24.1, MSE = 0.001, p < .001, \eta^2_p = .39 \), indicating higher error rates in switches than in repetitions (6.1\% vs. 4.6\%) and thus switch costs of 1.5\%. The interaction of auditory attention shift with age group was not significant, \( F < 1 \), indicating the switch costs for older and young adults were numerically very similar (1.3\% vs. 1.8\%, respectively; i.e., error switch costs were numerically even somewhat smaller in older adults). Also, the effect of CSI was significant, \( F(1, 37) = 8.1, MSE = 0.005, p < .05, \eta^2_p = .18 \), indicating a preparation benefit (0.8\%), but the interaction of auditory attention shift and CSI was significant, too, \( F(1, 37) = 9.0, MSE = 0.001, p < .05, \eta^2_p = .20 \), indicating smaller switch costs for long CSI than for short CSI (0.7\% vs. 2.3\%) and thus a preparatory reduction of switch costs. Importantly, CSI interacted with age group, \( F(1, 37) = 6.2, MSE = 0.001, p < .05, \eta^2_p = .14 \), indicating a larger general preparation benefit for older adults than for young adults (1.5\% vs. 0.1\%).

The main effect of congruency was significant, \( F(1, 37) = 37.9, MSE = 0.001, p < .001, \eta^2_p = .51 \), indicating a substantial congruency effect of 3.9\%. The congruency effect did not interact with auditory attention shift, \( F(1, 37) = 1.9, MSE = 0.001, p > .05, \eta^2_p = .05 \), and CSI, \( F < 1 \). The three-way interaction with auditory attention shift, CSI, and congruency was not significant, \( F < 1 \). Likewise, the interaction of congruency with age group was not significant, \( F(1, 37) = 2.5, MSE = 0.003, p > .05, \eta^2_p = .06 \). The three-way interactions with age group and the four-way interaction were also not significant, \( F < 1.7 \).

Dichotic listening procedures allow for the examination of auditory laterality and hemispheric asymmetry, such as the right-ear advantage (REA). It is a well-documented finding in dichotic listening that right-handed participants report more accurately information presented to the right ear than to the left ear (Kimura, 1961; see Hugdahl, 2011, for a review). We therefore examined the REA in a supplemental analysis. We excluded data from three left handers from this analysis. RTs and error rates were submitted to separate ANOVAs using relevant ear, auditory attention shift, congruency, and age group as independent variables (i.e., collapsing the data across CSI to obtain a sufficiently large number of observation in each condition). We only report the relevant main effects and interactions regarding the REA.

For the RT analysis, the main effect of relevant ear was not significant, \( F(1, 34) = 1.3, MSE = 34,556, p > .05, \eta^2_p = .04 \), and neither was the interaction of relevant ear and age group, \( F < 1 \), but the interaction of relevant ear and auditory attention shift was significant, \( F(1, 34) = 14.7, MSE = 4,273, p < .05, \eta^2_p = .30 \), indicating that the switch costs were smaller for the right ear than for the left ear (106 vs. 165 ms). The interaction of relevant ear and congruency was not significant, \( F(1, 34) = 2.5, MSE = 3,157, p > .05, \eta^2_p = .07 \), neither was the three-way interaction with age group, \( F(1, 34) = 1.2, MSE = 3,157, p > .05, \eta^2_p = .04 \).
For the error rates, neither the main effect of relevant ear was significant, $F(1, 34) = 2.7$, $MSE = 0.001$, $p > .05$, $\eta^2_p = .07$, nor the interaction of relevant ear and age group, $F(1, 34) = 1.5$, $MSE = 0.001$, $p > .05$, $\eta^2_p = .04$. The interaction of relevant ear and auditory attention shift was not significant, $F < 1$; however, the interaction of relevant ear and congruency was significant, $F(1, 34) = 9.1$, $MSE = 0.001$, $p < .05$, $\eta^2_p = .21$, indicating that the congruency effect was smaller for the right ear than for the left ear (2.0% vs. 5.7%). The three-way interactions were not significant, $F < 1$.

This supplemental analysis demonstrates that our paradigm is sensitive to the REA. The reduced RT switch costs and reduced congruency effect in error rates at the right ear relative to the left ear suggests a better or more complete attentional biasing for the right ear, so that task-irrelevant information presented to the left ear is less interfering. Yet, this REA did not differ across age groups, thus supporting our main finding of unimpaired auditory attention switching in older adults.

**DISCUSSION**

The aim of our study was to examine whether there are age-related task-switching differences in the auditory modality. More specifically, we examined whether the ability to prepare for an upcoming auditory attention shift differs between young and older adults. To this end, we used a novel paradigm that combined methodologies of dichotic listening and task switching (Koch et al., 2011). We found clear performance costs with instructed attention switches. These auditory attention switch costs were decreased with prolonged CSI. Also, the participant’s performance was better in congruent trials than in incongruent trials. Importantly, these three effects were similar in both age groups.

The finding of substantial costs of intentional shifting of auditory attention (i.e., switch costs) replicates the finding of Koch and colleagues (2011) with young adults. To account for these findings, Koch and colleagues (2011) proposed that the observed auditory switch costs can be taken to reflect, at least partly, the process of switching auditory selection criteria and suggested that the observed auditory switch costs refer to relatively abstract attentional settings.

Theories of cognitive control in task switching assume a role of inhibitory processes in switch costs (Koch, Gade, Schuch, & Philipp, 2010; Mayr & Keele, 2000). Arguably, inhibition of competing perceptual filter settings is important in our task. In fact, several theories of aging assume that the ability to inhibit irrelevant information declines with age (Braver & Barch, 2002; Hasher, Tonev, Lustig, & Zacks, 2001; Hasher & Zacks, 1988; Hasher, Zacks, & May, 1999). Therefore, one might have expected age-related differences in switch costs. However, the auditory switch costs in older adults in this study were of similar size compared with the auditory switch costs in the young adults, suggesting no age-related differences in task switching in the auditory modality. Assuming that inhibitory processes contribute to auditory switch costs, the results of our study are not in line with predictions from the inhibitory deficit theory.

This conclusion is also supported by findings of studies that more directly focused on task inhibition. Mayr (2001) and Lawo and colleagues (2012) conducted studies in which older and young adults switched among three visual tasks and examined potential age-related inhibitory deficits in task switching assessing $n – 2$ task repetition costs.
(Mayr & Keele, 2000). $n - 2$ task repetition costs refer to the performance impairment in sequences of the ABA type (i.e., $n - 2$ task repetition) relative to the CBA type (i.e., $n - 2$ task switch), which can be interpreted in terms of persisting inhibition of previously abandoned tasks. $n - 2$ task repetition costs have been demonstrated in many studies (see Koch et al., 2010, for a review). However, Lawo and colleagues (2012) observed $n - 2$ task repetition costs that did not differ across age groups, and also Mayr (2001) did not find reduced $n - 2$ task repetition costs in older adults. These findings do not support a strong role of an age-related deficit in task inhibition.

Even though the present result represents a null effect, it nevertheless seems to us to be very suggestive. The statistical power to detect larger auditory switch costs for older adults than for young adults does not exceed .70 with our sample sizes (Faul, Erdfelder, Lang, & Buchner, 2007), but the proportional RT switch costs (i.e., taking baseline RT differences into account) were almost identical (11.7% vs. 11.8%), and the error switch costs were numerically below that of the young adults. Also, our finding of no age-related differences in switch costs is entirely in line with the general meta-analytic observation of Wasylyshyn and colleagues (2011). Therefore, based on the fact that almost all of the existing task-switching studies examining age-related differences have used visual tasks, this study represents an important extension to auditory attention tasks.

Even though most of the previous studies used visual tasks, the study by Tun and Lachman (2008) is a notable exception. The authors examined age-related differences in switch costs in the auditory modality and found larger switch costs for older compared with young adults. However, that study examined switching between response mappings (i.e., S–R mapping reversal). In contrast, our study examined switching between auditory selection criteria with constant S–R mapping reversal. In addition to possible age effects in auditory attention switch costs, we also examined preparation processes. We found that the sizes of the preparation effects in RT were similar across age groups. Error rates showed an even increased preparation effect in old age, but this particular effect is not consistent with the existing literature on task switching using visual tasks. Also, using three visual tasks, Lawo and colleagues (2012) found significantly decreased RT preparation benefits in old age. Therefore, the empirical evidence seems to be mixed at this point. It is possible that the present relative preparation benefit in error rates for older adults is due to the auditory modality, but we refrain from suggesting a specific interpretation of this age-specific difference in the preparation effect given that this isolated effect was not backed up by a similar data trend in RTs.

Moreover, the reduction of switch costs with prolonged preparation time was very similar across age groups both in RT and error rates. This finding is in line with other aging studies that showed that the preparatory reduction of switch costs with two tasks is not impaired in older adults (Cepeda, Kramer, & Gonzalez de Sather, 2001; Hartley et al., 1990; Hsieh & Wu, 2010; Kramer et al., 1999; Meiran et al., 2001).

We also found substantial congruency effects in both RT and error rates, but the pattern of interaction was not very clear (i.e., smaller congruency effect in switches), and it was not very consistent in our earlier study (Koch et al., 2011) either. Nevertheless, one might speculate that increased attentional control in switch trials more effectively blocks out processing of the irrelevant auditory information (leading to reduced congruency effects in switches). Yet, studies using visual tasks often found increased congruency effects in switches (see Kiesel et al., 2010, for a review). Moreover, Meiran and colleagues (2001) found increased congruency effects in older adults in visual task switching, but in this study the pattern of congruency effects was the same in both age groups. Further studies would have to clarify this issue.

Note that earlier studies using dichotic listening procedures found that older adults perform worse compared with young adults when reporting relevant information in the presence of distracting information presented to the other ear (Gootjes, Van Strien, & Bouma, 2004; Passow et al., 2012). Moreover, right-handed people typically report information presented to the right ear more accurately than information presented to the left ear, and this REA is a well-documented finding of auditory laterality and hemispheric asymmetry in dichotic listening (Kimura, 1961; see Hugdahl, 2011, for a review). Whereas most studies on the REA are single-task ones assessing memory performance, our study showed that the advantage extends to auditory switch costs. However, the modulation of performance costs by ear did not differ between young and older adults, further supporting the similarity of switch-related processes in auditory attention switching tasks across age groups.

In sum, using a novel auditory task-switching paradigm, we found substantial costs of intentional switching auditory attention from one speaker to another speaker. However, we did not find evidence for an age-related decline in the ability to intentionally shift auditory selective attention.

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