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Task Switching Across the Life Span: Effects of Age on General and Specific Switch Costs

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The authors investigated age-related changes in executive control using an Internet-based task-switching experiment with 5,271 participants between the ages of 10 and 66 years. Speeded face categorization was required on the basis of gender (G) or emotion (E) in single task blocks (GGG. . . and EEE. . .) or switching blocks (GGEEGGEE. . .). General switch costs, the difference between switching block and single task block performance, decreased during development and then increased approximately linearly from age 18. In contrast, specific switch costs, the difference between switch trial and nonswitch trial performance in the switching block, were more stable across the same age range. These results demonstrate differential age effects in task-switching performance and provide a fine-grained analysis of switch costs from puberty to retirement.

Keywords: task switching, executive control, switch costs, aging

Executive control processes are, at their most general, described as high-level functions that organize, sequence, and regulate behavior. They are vital for most everyday activities, particularly those that require planning, holding open multiple goals, or maintaining cognitive flexibility. Executive control is a complex notion, and it is clear that it consists of several separable functions. For example, Miyake et al. (2000) demonstrated three separable factors underlying performance on tasks requiring executive control: mental set shifting, information updating, and inhibition of prepotent responses.

There is a large body of evidence showing age-related differences in executive control performance. In general, performance on tasks requiring aspects of executive control improves through childhood and adolescence (for a review, see Zelazo & Müller, 2002). Similarly, performance deteriorates above age 60, as evidenced by performance on several measures, including the Wisconsin Card Sorting Test (Fristoe, Salthouse, & Woodard, 1997), the Stroop task (Uttl & Graf, 1997; but see Verhaeghen & De Meersman, 1998), and verbal fluency (e.g., Isingrini & Vazou, 1997). These developmental improvements, along with aging-related decline, together give an inverted-U-shaped function of cognitive control with age, similar to inverted-U-shaped functions found in several other areas of performance with age (e.g., processing speed, Kail & Salthouse, 1994; task coordination, Mayr, Kliegl, & Krampe, 1996; and inhibitory control, Williams, Ponesse, Schachar, Logan, & Tannock, 1999).

Recently, task switching has become a popular method for examining an aspect of executive control (Allport, Styles, & Hsieh, 1994; Rogers & Monsell, 1995). In a typical task-switching procedure, participants switch between two orthogonal classifications of stimuli. For example, they might be presented with a stimulus that could be a red triangle, a blue triangle, a red circle, or a blue circle and have to perform two color classifications followed by two shape classifications. Two measures of executive control in task switching are generally considered: general switch costs (the difference between performance in switching blocks and performance in blocks containing only one task) and specific switch costs (the difference between performance on switch trials and performance on nonswitch trials in a switching block). General switch costs (also known as mixing costs or set selection costs) reflect the difficulty in maintaining and selecting among two or more different potential response sets. Specific switch costs represent the difficulty in switching from one response set to another.

General and specific switch costs do not show the same age-related differences. Even taking into account age-related slowing, general switch costs are larger for older people than for younger people (Kray & Lindenberger, 2000; Mayr, 2001; Van Asselen & Ridderinkhof, 2000). General switch costs also suggest a developmental inverted-U-shaped function to executive control: Kray, Eber, and Lindenberger (2004) found that children and older adults showed larger general switch costs than did young adults. On the other hand, specific switch costs are largely unrelated to age when general age-related slowing is taken into account (e.g., Brinley, 1965; Kray & Lindenberger, 2000; Mayr, 2001; Mayr & Kliegl, 2000; Salthouse, Fristoe, McGuthry, & Hambrick, 1998).

However, there are studies showing different age effects on general and specific switch costs. For example, Van Asselen and Ridderinkhof (2000) found that when the switch was unpredictable, older adults' specific switch costs were larger than those of

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younger adults. Kray, Li, and Lindenberger (2002) found significant adult age-related differences in specific switch costs, but nonsignificant age-related effects on general switch costs, when switches between tasks were unpredictable and externally cued.

Many researchers have attempted to explain the U-shaped function of executive control with age in terms of frontal lobe functioning. Evidence from multiple sources such as functional imaging (e.g., DiGirolamo et al., 2001; Osmon, Zigun, Suchy, & Blint, 1996; Postle, Berger, & D'Esposito, 1999) and neuropsychological studies (e.g., Stuss, Eskes, & Foster, 1994; Tranel, Anderson, & Benton, 1994) has supported the wide agreement that tasks requiring some form of executive control depend on the use of (at least a part of) the frontal lobes (e.g., Baddeley & Della Sala, 1996; Duncan, 1995; Miller & Cohen, 2001; Roberts & Pennington, 1996). In children, frontal lobe development continues through adolescence over the same developmental time as performance on executive control tasks improves (Davies & Rose, 1999). Frontal lobe deterioration occurs in old age, a time during which, as we have seen, executive control also decreases, and age-related decline in frontal lobe functioning is a well-accepted explanation for decline in executive control (e.g., Duncan, 1995; Raz, 2000; West, 1996).

However, if changes in frontal lobe functioning mediate the inverted-U-shaped function of executive control with age, one might predict a decline in performance before old age. For example, the size of neurons in the frontal lobes changes from the age of 45 (Haug & Eggers, 1991), and blood flow in the frontal lobes declines between the ages of 19 and 50 (Schultz et al., 1999).

At present, there is limited evidence on the way in which executive control changes across the life span. Most existing studies use two or three groups for comparison (e.g., children, young adults, and older adults). The only study we know of to use a more fine-grained approach to task switching (Cepeda, Kramer, & Gonzalez de Sather, 2001) showed a U-shaped effect of age on reaction time and suggested a similar effect in switch costs across 10-year bins. Although there was evidence for a general inverted U shape to executive control, the low numbers of participants per cell made it difficult to trace age effects on executive control outside the extremes of childhood and old age. Cepeda et al.'s (2001) conclusion was that "switch costs decreased from childhood to young adulthood, remained fairly constant across the adult years, and then began to increase after the age of 60" (p. 726).

The few studies that have specifically included a middle-aged group for comparison with younger or older participants have found executive control decrements in middle-aged participants. Garden, Phillips, and MacPherson's (2001) investigation into performance on the Wisconsin Card Sorting Task and the Self-Ordered Pointing Task revealed that middle-aged participants (53–64 years old) were significantly worse at both tasks than were younger participants (30–46 years old). Kray and Lindenberger's (2000) study was one of the few on task switching to include middle-aged adults. In their study, general switch costs in middle-aged participants (41–60 years old) were higher than those of younger participants (20–40 years old) and appeared to be more similar to the older group (61–80 years old) than to the younger group.

In summary, there is strong evidence that executive control improves through childhood and adolescence and declines in old age, but it is unclear whether age effects are found throughout young adulthood and middle age. One of the major aims of our study was to address this issue by examining both general and specific switch costs across the life span.

The Present Study

We used the first author's involvement with a British Broadcasting Corporation television (BBC TV) series to recruit a large number of participants for an online experiment. At the end of each episode, 4 million viewers were encouraged to visit a website that included the present study. By using several thousand participants varying in age, it was possible for us to investigate the effect of age on switch costs in detail. The flip side of this Web-based methodology was that there was no way to control conditions under which the task was completed or to filter out participants who were, for example, lying about their age or gender, who were not taking the task seriously, who failed to understand the task instructions, or who were intoxicated. However, given the large number of participants, we were able to be very conservative in the data sets we allowed to enter the analysis, which reduced potential systematic effects on the results. That said, a Web-based methodology is still subject to a lot of random noise: the effects of different computer types, operating systems, monitor sizes, the time of day, different hand positions, distractions, and background noise, among other things. Thus, in general, this type of procedure tends to produce effects that account for a small proportion of the variance but are highly significant. We believe that Web-based testing is now well enough documented not to require detailed justification here. In designing the experiment, we were mindful of the guidelines set out in the work of Birnbaum (2000) and Reips (2002).

Method

Participants

A total of 12,103 data sets were collected over the course of 4 months.

Stimuli

Four photographs were used as stimuli: a happy female, a sad female, a happy male, and a sad male. Each picture was 195 × 250 pixels in size. Pictures were taken with a black background and were cropped so that long hair and neck were largely not visible (see Figure 1 for an example).[1]

Measures

We considered (a) demographic data and (b) task-switching data. The experiment also contained measures of impulsivity and financial decision choices, which are reported elsewhere. Measures not reported here were uncorrelated with task-switching performance.

The following demographic data feature in the analyses: age (in years) and gender (male, female). Education—secondary school (12 years), sixth form (14 years), or degree (17 years)—was also requested and appears in the descriptive statistics, along with the analysis of the over-18 data that follows. Education is not included as a factor for analyses that include under 18s, as it is confounded with age in younger people.

There were three stages to the task-switching component of the data collection: two single task blocks and a switching block. The single task blocks comprised 12 trials in which participants categorized a face as

[1] It was not possible to use standard face images featured in other studies of face processing, for example, Ekman faces, because the images were displayed on a freely accessible website, creating a possible risk of copyright infringement.

Figure 1. Example of screen display during switching block.

happy or sad on every trial or as male or female on every trial. The type of classification block (gender or emotion) to appear first was randomized between participants. The switching block was of an AABB design and comprised 8 sets of 4 trials. Each set of 4 trials consisted of two gender classifications followed by two emotion classifications or vice versa. The type of trial to appear first was randomized between participants. Within each block, each of the four faces appeared equally often. Although the structure makes for a highly regular and predictable sequence of classifications, the relatively small number of trials prevents it from becoming so automatic as not to require executive control.

Procedure

A 550- × 440-pixel Macromedia Flash movie was centered in a black HTML Web page. After viewing the first page, which described the experiment and encouraged participants to take the task seriously, participants were given the opportunity to provide demographic information if they wished to. There then followed the two single task blocks and the switching block, always in that order. Participants received instructions at the start of each block indicating the task they would be doing, and they were informed they would have to press either the *Z* key or the *M* key to respond. At the start of the single task block, four types of information were displayed on the screen:

1. In the center of the screen was a circle in which the faces would be displayed.

2. At either side of the screen was the appropriate response key. The letter *Z* was displayed on the left side of the screen, and the letter *M* was displayed on the right side of the screen.

3. Below each letter was the criterion for pressing the letter. Thus, for the gender task, the word *male* appeared under one of the letters, and the word *female* appeared under the other letter.

4. In the bottom center of the screen was the word *gender* or *emotion* to cue participants to the task at hand.

These four types of information remained on the screen throughout each single task block. Each trial in the single task block began with a 1,000-ms delay, after which one of the four face stimuli flashed on the screen for approximately 175 ms.[2] Participants then pressed a key to indicate the category corresponding to the face just shown. If a response was incorrect, a large text box containing the word *OOPS!* appeared in the middle of the circle for 1,000 ms to inform participants of their error, followed immediately by the next trial. A correct response was immediately followed by the next trial.

Before the switching block started, participants were informed that they would alternate between two male–female trials and two happy–sad trials. At the start of the switching block, three things were displayed on the screen: (a) the circle, as before; (b) the letters *Z* and *M,* as before; and (c) criteria in both tasks for pressing each letter. At the start of each trial, there was a 250-ms pause—a response–cue interval (RCI) —after which the cue *gender* or *emotion* also appeared in the bottom center of the screen. The cue–target interval (CTI) was 1,000 ms, after which a stimulus flashed on the screen for approximately 175 ms. Figure 1 shows a representative screenshot. When the participant pressed one of the response keys, the cue disappeared from the screen. As in the single task blocks, if a response was incorrect, a large text box containing the word *OOPS!* appeared for 1,000

[2] It was not possible to control display durations with millisecond accuracy. Response time (RT) was recorded to the nearest millisecond, although it is likely to be subject to more random noise than comparable experiments that use specific testing software. However, see Ulrich and Giray (1989) for evidence that a lack of millisecond accuracy makes little difference to results anyway.

ms, followed immediately by the next trial. A correct response was immediately followed by the next trial.

At the end of each block, participants were shown their mean response time (RT). On completion of the experiment, a participant's responses were passed to a Perl script, which stored the data with the participant's IP address on a central server. Participants then saw average results for people who had already taken part in the experiment.

Results

We excluded the following data: 3,964 submissions from IP addresses for which data had already been received, 40 submissions in which the data set was corrupt or incomplete, and 1,690 submissions in which the participant did not give his or her age. Submitted ages ranged from 5 to 109 years. If there were fewer than five exemplars for a particular age, all exemplars for that age were discarded, leaving a range of ages from 10 to 66. This removed 28 data sets from the analysis. Of those who remained in the analysis, 55% of participants described themselves as female, and 45% described themselves as male. With respect to education, 30% had 12 years of education, 25% had 14 years of education, and 45% had 17 years of education. We included 6,381 data sets in this stage of the analysis.

Task Acquisition

The rate at which participants learned each task was used to determine the trials to be included in subsequent analyses and to reveal age differences in task acquisition. Participants were divided into four age groups: 10–17 years, 18–30 years, 31–45 years, and 46–66 years. In these analyses we included only correct responses that did not immediately follow an error. Median RTs for each of the trials in a block are displayed in Figure 2. (Error rate data followed similar patterns and are not discussed here.)

For the 12 emotion classification trials (see Figure 2a), it is clear that performance improved over Trials 1–4, after which RT was more constant. More important, as we are interested in the effect of age on performance, between Trials 5 and 12 there appeared to be no interaction between age group and trial number. We therefore excluded Trials 1–4 from subsequent analysis, confident that we were not biasing our estimates of performance in favor of any particular age group. Here and elsewhere, the number of trials excluded as practice did not affect the overall pattern of results.

A similar set of results can be seen for the 12 gender classification trials in Figure 2b. Using the same rationale, we excluded Trials 1–4 from subsequent analysis. Finally, the trial-by-trial RT data for performance in switching blocks are given in Figure 2c (RT on switch trials) and Figure 2d (RT on nonswitch trials). There was some evidence of an interaction between age group and trial number: By the final trial, the two younger groups were near asymptote, whereas the older group was still improving. Thus, any conclusions about the RTs of older people carry the caveat that performance might have improved further with more practice. To minimize effects of task acquisition rate, we excluded Trials 1–6 from subsequent analysis of switching blocks.

Effects of Age on Performance

In the RT analysis, we excluded RTs of more than 3,000 ms and responses that were erroneous or immediately followed an error. Averages reported are means of participant means.[3] Using the data excluding the first few trials (see above), we excluded the following participants: (a) those whose error rate in any block was greater than 25%, and (b) those who did not submit their gender and education level. This exclusion left 5,271 data sets in the analysis. RTs by age are given in Figure 3. Error rates by age are given in Figure 4.

Effects of Age on RT and Error Rate

The analysis of age effects on RT and error rate took two forms. First, we determined whether performance followed a U-shaped function. We then used an ANOVA to look at the interactions between age and gender, grouping participants into 14 age categories as shown in Table 1.[4]

Polynomial regressions were carried out on the RT and error rate data for all conditions. Age and age-squared terms were used in the regression to test for U-shapedness. For RT, the models were all significant fits, R^2_{adj} = .02, .03, and .06, for emotion, gender, and switching blocks (adj = adjusted), respectively; $F(2, 5268) =$ 61.20, 93.24, and 170.93, respectively, all $ps < .0001$. Age was a significant unique predictor of RT for the emotion and gender blocks, $F(1, 5268) = 6.54$, and $F(1, 5268) = 27.88$, $ps < .01$, but not for the switching block, $F(1, 5268) = 2.38$, $p = .12$. Age squared was a significant unique predictor for the emotion, gender, and switching blocks, $F(1, 5268) =$ 22.39, 60.46, and 28.38, respectively, all $ps < .0001$. For error rates, the models were all significant fits, R^2_{adj} = .008, .01, and .02, for emotion, gender, and switching blocks, respectively; $F(2, 5268) =$ 23.38, 27.23, and 47.65, respectively, all $ps < .0001$. For all three blocks, both age and age squared were significant unique predictors of error rate, $F(1, 5268) =$ 25.98, 20.02, and 90.20, all $ps < .0001$; and $F(1, 5268) =$ 16.34, 34.44, and 77.85, all $ps < .0001$, respectively.

To summarize, there was a significant quadratic component linking age and both RT and error rate measures of performance, suggesting a significantly U-shaped function. The next stage was to use the grouped age data to look at the interaction between age and gender with respect to RT and error rate. We combined the age data into the groups shown in Table 1 to conduct an ANOVA. This method makes no assumptions about the function mapping age to RT or errors while retaining an adequate number of data points per cell, and it allows comparison with the most similar study on aging across the life span (Cepeda et al., 2001), which used similarly "binned" ages.

Separate ANOVAs were performed on the RT data for single task emotion, single task gender, and switching blocks (see Figure 3), with factors of age group and gender. In all cases, of course, the effect of age was highly significant (all $ps < .001$). We focus here on the effect of gender and its interaction with age. For RT, female participants were on average 19 ms and 15 ms faster than male participants for single task emotion and single task gender blocks, respectively, $F(1, 5192) = 9.86$, and $F(1, 5192) = 12.47$, $ps <$

[3] The patterns of results were the same when medians were used in place of means.

[4] An ANOVA is necessary because investigating interactions between terms in a polynomial fit and other factors such as gender makes psychological interpretation of any significant interactions very difficult.

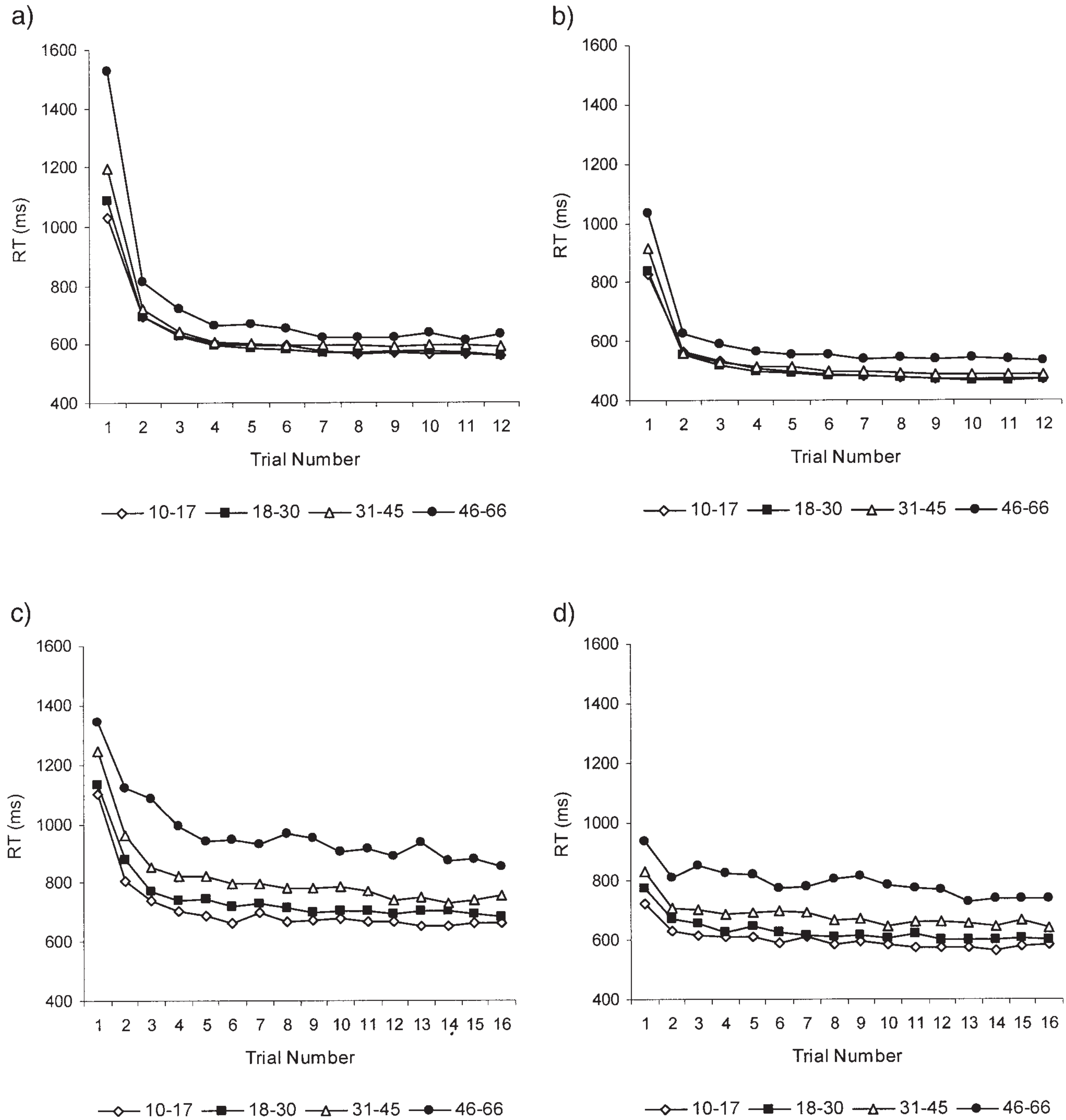

Figure 2. Trial-by-trial median response times (RTs) for four different age groups: 10–17, 18–30, 31–45, and 46–66 years old for (a) single task emotion classifications, (b) single task gender classifications, (c) switching block switch trials, and (d) switching block nonswitch trials.

.002, but there was no effect of gender for switching blocks. There was no interaction between age and gender for any of the blocks. With error rate as the dependent variable, the only significant effect involving gender was for the switching block, $F(1, 5192) = 6.14$, $p < .01$, where the error rates were .078 and .081 for female and male participants, respectively.

Effects of Age and Gender on General and Specific Switch Costs

There are four types of trials considered in the analyses that follow: emotion classifications in the emotion-only single block (E), gender classifications in the gender-only block (G), switch

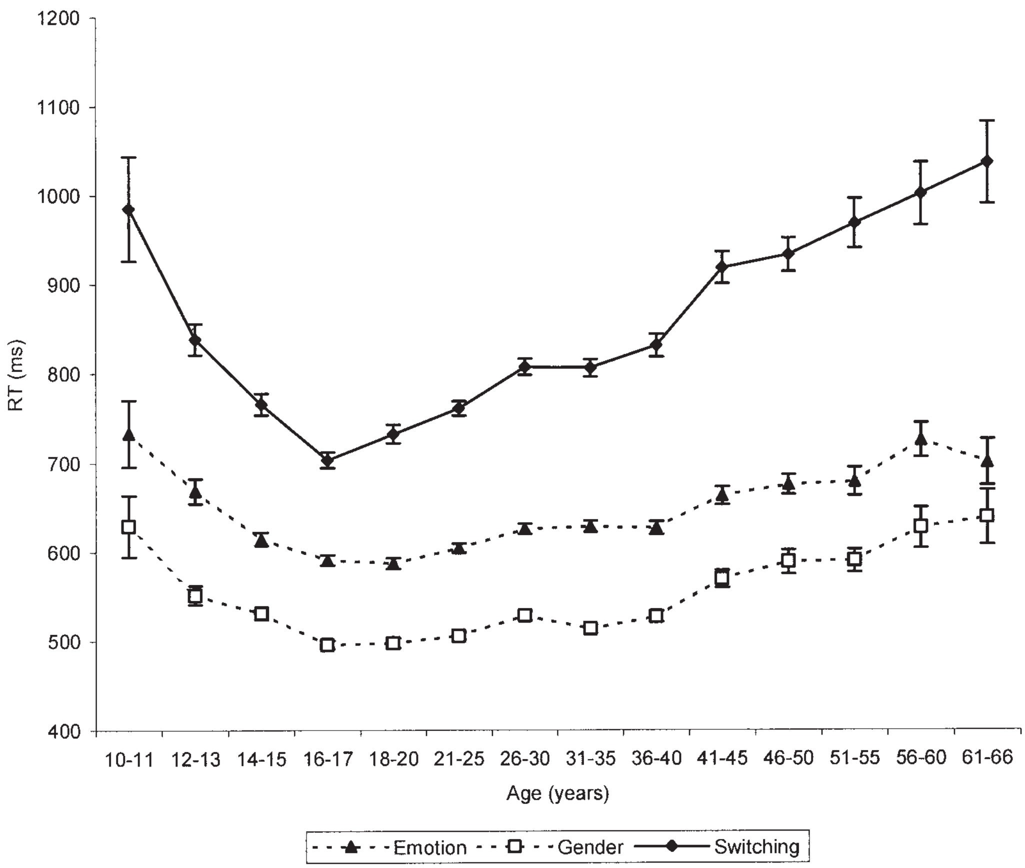

Figure 3. Mean of individual participants' mean response times (RTs) for emotion, gender, and switching blocks. Error bars represent the standard error of the mean.

trials (emotion or gender) in a switching block (Sw), and nonswitch trials (emotion or gender) in a switching block (NSw). General switch costs were calculated for each participant by subtracting the average of E RT and G RT from NSw RT.[5] Specific switch costs were calculated for each participant by subtracting NSw RT from Sw RT. The effect of age on general and specific switch costs is shown in Figure 5.

We investigated the effects and interactions of age and gender using ANOVAs. For the general switch cost RT data, there was a main effect of age, $F(13, 5243) = 12.42$, $p < .001$; a main effect of gender, $F(1, 5243) = 6.49$, $p = .01$; and a small but significant interaction between age and gender, $F(13, 5243) = 1.74$, $p = .05$. Male participants showed smaller general switch costs than did female participants by approximately 20 ms, and the interaction suggested that general switch costs increased more rapidly throughout adulthood in women than in men. The same effects and interactions remained when proportionate general switch costs was used as the dependent measure (see Figure 6), with a main effect of age, $F(13, 5243) = 9.13$, $p < .001$; a main effect of gender, $F(1, 5243) = 11.50$, $p = .001$; and a small but significant interaction between age and gender, $F(13, 5243) = 1.75$, $p = .05$.

For the specific switch cost RT data, there was a main effect of age, $F(13, 5243) = 2.16$, $p = .009$; no effect of gender; and no interaction. This age effect was no longer significant with proportionate specific switch costs as the dependent measure (Fs < 1).

The error rates showed only small effects of age and gender on switch costs. General switch costs as measured by error rates were affected only by gender, $F(1, 5243) = 4.29$, $p = .04$, with male participants showing larger error rate switch costs than did female participants. Specific switch costs as measured by error rates showed a small effect of age, $F(13, 5243) = 1.75$, $p = .05$, and followed a similar pattern to that of RTs.

As switch cost effects were seen predominantly in the RT rather than in the error data, we concentrate on the RT results from here on. Breaking the RT data down further to investigate the relative difficulty in switching to an emotion trial and a gender trial, we found that Sw RT for emotion trials was 893 ms, NSw RT for emotion trials was 785 ms, Sw RT for gender trials was 798 ms, and NSw RT for gender trials was 714 ms. General switch costs for emotion were 163 ms, and those for gender were 189 ms, a significant difference, $t(5262) =$

[5] Other studies calculate general switch costs as ½(NSw + Sw) − ½(E + G) or Sw − ½(E + G). But this conflates general and specific switch costs. A person whose performance on nonswitch trials was identical to that in a single task block, but who had large specific switch costs, would also show moderately large general switch costs. However, given that specific switch costs are relatively constant across age, the way in which general switch costs are calculated does not affect the trends in the results—it merely increases the absolute values of all general switch costs (see Kray et al., 2004, 2002).

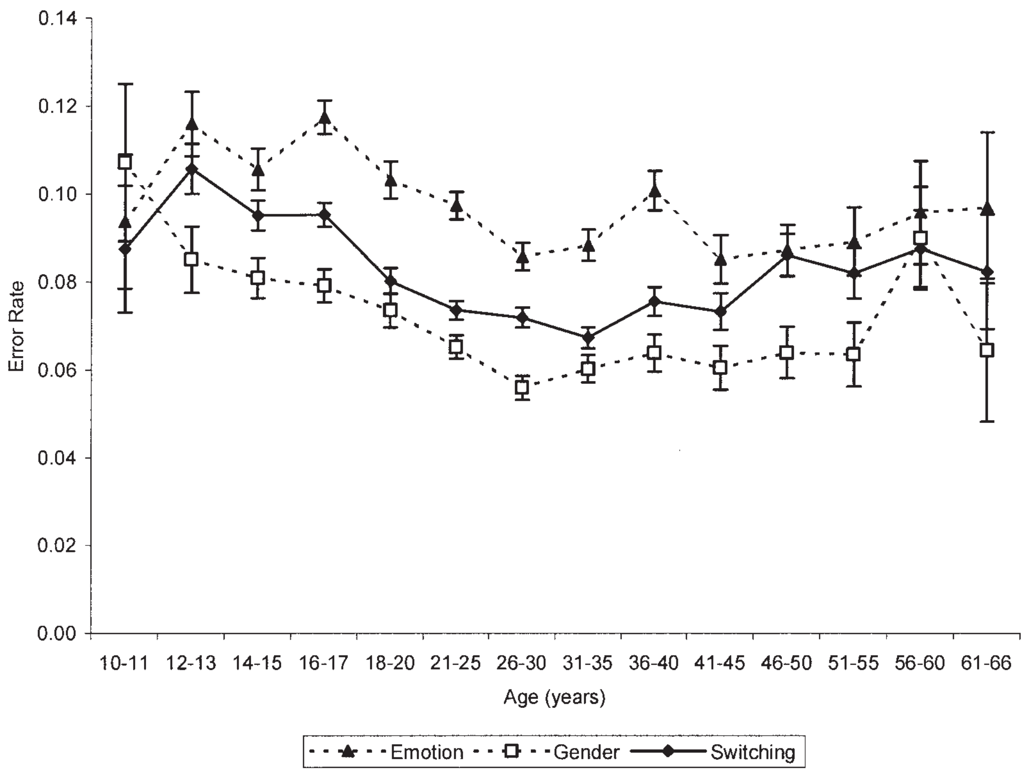

Figure 4. Mean of individual participants' mean error rates for emotion, gender, and switching blocks. Error bars represent the standard error of the mean.

6.63, $p < .001$. Specific switch costs for emotion trials were 108 ms, and those for gender trials were 84 ms, also a significant difference, $t(5262) = 5.28$, $p < .001$.[6] For the emotion task, there was a reliable interaction between age and gender for specific switch costs, $F(13, 5235) = 2.56$, $p = .002$. Although the data at this level of analysis are noisy, it appears that female participants showed smaller specific switch costs for emotion than did male participants through adolescence but that this effect disappeared, and was even reversed, in adulthood. All other analyses in which switch block gender and emotion performance were analyzed separately showed either no main effect of age or gender or interactions, or they showed the same effect as found in the data collapsed across task type, and hence are not reported here.

Trends in Switch Costs Across Childhood and Adulthood

It is clear from Figure 5 that our data showed a reduction in general switch costs from 10 to 17 followed by a gradual increase from 18 to 66. In this next stage of analysis, we investigated whether these effects were significant by splitting the data into under-18 and over-18 groups and using two general linear models with age as a continuous variable. There are three reasons for this approach rather than, say, a nonlinear regression. First, we were interested in whether the developmental and aging effects on switch costs were significant. An analysis fitting a single function to the life span data could not reveal whether developmental or aging trends in isolation are significant. Second, we were dealing with two distinct phenomena: development of task-switching ability and its decline. From a theoretical perspective, fitting these data with a single function seemed inappropriate.[7] Third, it was apparent (see Figures 5 and 6) that general switch costs decrease roughly linearly through adolescence and increase approximately linearly through adulthood. Thus, linear function fits seemed appropriate.

Adolescent data. To analyze the data for under 18s, we constructed a general linear model with continuous variable age and categorical variable gender to analyze the trends in general and specific switch costs. Education was not included because it was confounded with age.

For general switch costs, the model was a significant fit, $R^2_{adj} = .01$, $F(3, 1197) = 6.58$, $p = .0002$. The only significant effect was that of age, $F(1, 1197) = 14.58$, $p < .0001$. For proportionate general switch costs, the model was a significant fit, $R^2_{adj} = .01$, $F(3, 1197) = 5.57$, $p = .0008$. Again, only age was significant, $F(1, 1197) = 7.58$, $p = .006$.

For specific switch costs, the model was not a significant fit,

[6] We had to exclude a further 8 participants from the analysis that split switching data into emotion and gender performance because their error rate made it impossible to estimate all of the cell means.

[7] An alternative would be to fit the data with, say, two exponentials (Cerella & Hale, 1994). This would have been appropriate if we had had a larger range of ages. However, over the range of ages we studied, there was no evidence of a nonlinear component to either adolescent development of task-switching performance or age-related decline in task-switching performance.

Table 1
Details of Participants in Each of 14 Age Groups

Measure	Age group (years)													
	10–11	12–13	14–15	16–17	18–20	21–25	26–30	31–35	36–40	41–45	46–50	51–55	56–60	61–66
N	28	166	380	627	503	914	853	678	411	279	215	122	64	31
M age (years)	10.8	12.6	14.6	16.5	18.9	23.1	28.0	32.9	37.8	42.7	47.9	52.8	58.1	62.9
M years of education						15.8	16.0	15.3	15.2	15.0	15.1	15.3	14.8	15.1
Gender (proportion)														
Girls and women	.61	.70	.68	.69	.54	.51	.53	.51	.48	.48	.51	.57	.51	.41
Boys and men	.39	.30	.32	.31	.46	.49	.47	.49	.52	.52	.49	.43	.49	.59

$R^2_{adj} < .001$, $F(3, 1197) = 1.63$, $p = .18$. The model remained a nonsignificant fit when proportionate specific switch costs was used as the dependent variable ($F < 1$).

Adult data. To analyze the data for over 18s, we constructed a general linear model with continuous variable age and categorical variables gender and education to analyze the trends throughout adulthood in general and specific switch costs.

For general switch costs, the model was a significant fit, $R^2_{adj} = .03$, $F(11, 4058) = 11.15$, $p < .0001$. There was an effect only of age, $F(1, 4058) = 85.30$, $p < .0001$, and no interactions among age, gender, and education. For proportionate general switch costs, the same pattern of significant results remained. The model was a significant fit, $R^2_{adj} = .02$, $F(11, 4058) = 8.68$, $p < .0001$. There was an effect only of age, $F(1, 4058) = 56.17$, $p < .0001$, and no interactions among age, gender, and education.

For specific switch costs, the model was a significant fit, $R^2_{adj} = .004$, $F(11, 4058) = 2.48$, $p = .004$. There was a significant effect of age, $F(1, 4058) = 12.86$, $p = .0004$, and no interactions among age, gender, and education. For proportionate switch costs, the model was not a reliable fit, $R^2_{adj} < .001$, $p = .71$.

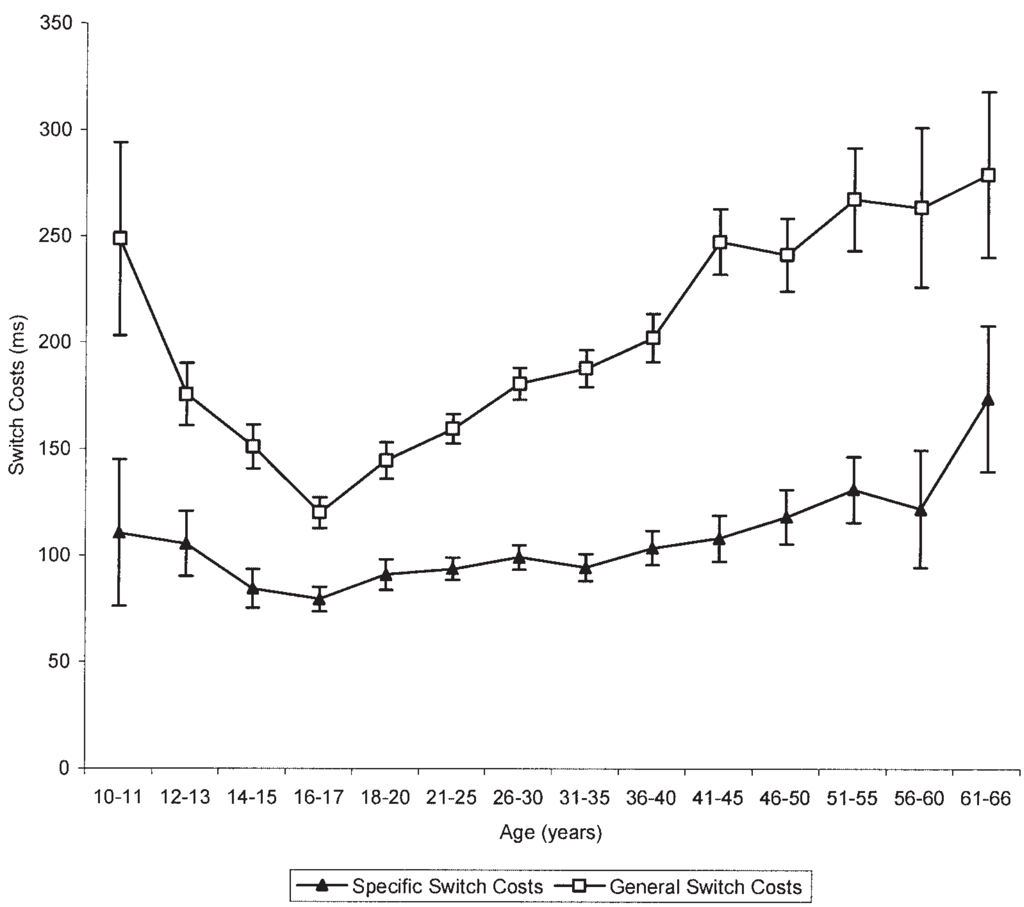

Figure 5. General and specific switch costs as a function of age group, as measured by response time differences. Error bars represent the standard error of the mean.

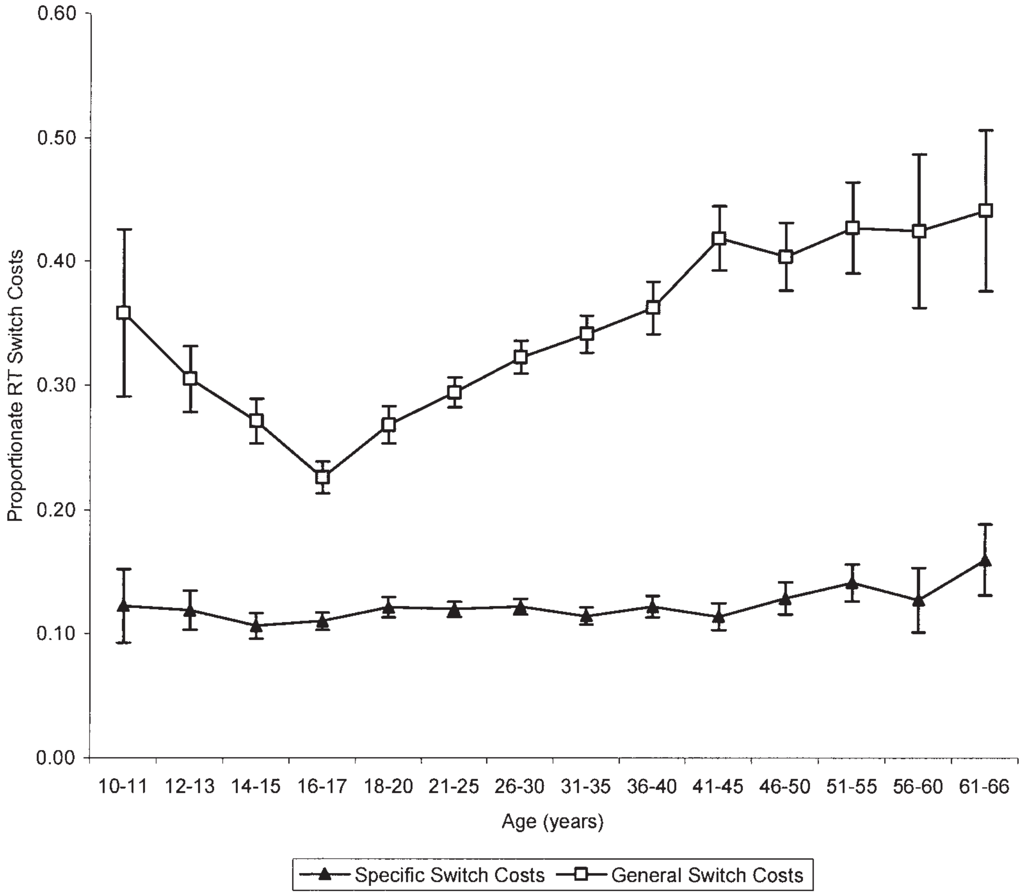

Figure 6. Proportionate general and specific switch costs as a function of age group, as measured by response time (RT) differences divided by baseline RT. The baseline for general switch costs was nonswitch block RT, and the baseline for specific switch costs was RT for nonswitch trials in a switching block. Error bars represent the standard error of the mean.

General Switch Costs in Young Adulthood

The general switch cost data in Figure 6 suggest that general switch costs start increasing from early adulthood. To test this, we constructed a general linear model with continuous variable age and categorical variables education and gender using the proportionate switch cost RT data from participants who were ages 18 to 40. The model was a poor fit but significant, $R^2_{adj} = .01$, $F(11, 3347) = 3.56$, $p < .0001$, and age was a significant predictor of proportionate general switch costs, $F(11, 3347) = 23.26$, $p < .0001$. There were no other significant effects.

Discussion

We used a large Internet study to investigate the way in which age affects performance in a task-switching paradigm. Our results, at the most crude level of analysis, are in agreement with previous research. RTs for single task and switching blocks followed a U-shaped function (see Figure 3), with children and older adult participants slower than young adults. Similarly, general switch costs decreased with age up to age 18 and increased with age through adulthood (see Figure 5), even when baseline RT was accounted for (see Figure 6). In contrast, specific switch costs were relatively unaffected by age (see Figures 5 and 6).

General Switch Costs and Aging in Adults

Our results demonstrate that age-related decrements in task-switching performance are found in early adulthood. General switch costs increased significantly from age 18 to age 40. This finding contrasts with at least some other findings in the cognitive aging literature demonstrating that performance declines little throughout most of adulthood but begins to accelerate above the age of 60 (e.g., Baltes & Lindenberger, 1997; Schaie, 1996). It is also at odds with Cepeda et al.'s (2001) conclusion that switch costs remained relatively constant between early adulthood and age 60, although it is possible that they referred to specific rather than to general switch costs.

Previous research indicates that we might have predicted aging effects in younger adulthood. Kray and Lindenberger's (2000) work demonstrated an increase in general switch costs between young adulthood and middle age, with no corresponding increase in specific switch costs, findings we have replicated and extended using our procedure.

Additionally, Cepeda et al.'s (2001) data give more support for an increase in switch costs throughout adulthood than their conclusion (above) suggests. Taking the data from their Table 3 and averaging across RCI and CTI and across session, we noted that general switch costs (i.e., RT for the first nonswitch trial following a switch trial in the switch block, minus RT for nonswitch trials in a nonswitch block) were 165 ms for 21–30 year olds, 195 ms for 31–40 year olds, 302 ms for 41–50 year olds, and 240 ms for 51–60 year olds. These results suggest that middle-aged adults may show a larger general switch cost than do younger adults. Thus, although we believe that our study is the first to demonstrate a clear effect of age on general switch costs in younger adults, this finding fits qualitatively with the results of existing research. Similarly, our results tie in with age effects on other measures of executive control. As we noted at the beginning of this article, Garden et al. (2001) found that middle-aged adults performed worse than young adults on the Wisconsin Card Sorting Task and the Self-Ordered Pointing Task. Of course, the upper age limit in our study was lower than in many cognitive aging studies. We are therefore unable to generalize beyond retirement age. However, we have been able to characterize effects over a wide adult age range (18–66 years old).

It should be noted that the mechanism behind our pattern of results, and those of others, is unclear. Performance on some tasks requiring executive control deteriorates through adulthood, whereas performance on others does not (Verhaeghen & Cerella, 2002). It has been argued that the observed pattern of age-related decline on certain tasks may reflect an inability to simultaneously maintain two task sets (Mayr, 2001; Verhaeghen & Cerella, 2002), rather than a decrement in executive control per se.

Development of Switching Ability in Adolescence

The pattern of general switch costs obtained here is similar to that obtained in previous studies measuring development of executive control. General switch costs decreased sharply with age between ages 10 and 17, suggesting development of (one aspect of) executive control throughout adolescence. We found it interesting that specific switch costs did not seem to show a similar developmental trend. It is possible that the data were too noisy to detect an underlying trend. However, given the relative insensitivity of specific switch costs to age in older adults as well, it seems likely that specific switch costs are less sensitive than general switch costs to the neurologic changes that occur across the life span.

Methodological Implications

This is, to our knowledge, the first attempt to run a task-switching experiment over the Web. There are, of course, many differences between online and laboratory-based experiments. For example, online participants are drawn from a more diverse population than are lab-based participants, who tend to be undergraduate students from relatively homogeneous backgrounds. Online experimentation does not allow strict control of stimulus size, monitor refresh rate, peripheral distractions, and participants' engagement with the task. However, it is pleasing to note that the results of this online study concur well with findings from lab-based studies with respect to general and specific switch costs, practice effects, and effects of age on switch costs. It therefore seems that switch costs are robust phenomena that can be observed in relatively uncontrolled circumstances. An online experimentation paradigm might, in future, be used more extensively to investigate task-switching in experiments that require a large number of participants or seek to investigate the effect of factors such as age, background, or personality on executive control.

Conclusion

The results of our study suggest that general switch costs decrease approximately linearly with age from ages 10 to 17, then increase linearly to age 66. We acknowledge the limited nature of the design: Further work might manipulate the predictability of the switches between tasks, the CTI, the RCI, practice, and the type of stimulus used. However, in the course of this article we hope we have done two things: first, demonstrated that age-related changes in switch costs between puberty and middle age are worthy of further investigation, and second, described a novel, Web-based methodology that can be used to investigate the matter further.

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