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Aging and Task Switching: A Meta-Analysis

Christina Wasylyshyn,

Naval Research Laboratory, Washington, DC

Paul Verhaeghen, and

School of Psychology, Georgia Institute of Technology

Martin J. Sliwinski

Department of Human Development and Family Studies, Pennsylvania State University

Abstract

A meta-analysis of 26 published articles (with 36 independent participant groups) was conducted to analyze the relationship between task-switching effects and aging. Latency served as the dependent measure. Multilevel modeling was used to test for additive and multiplicative complexity effects in local and global switch costs. Global task switching was found to add 1 or more stages to processing and resulted in a marked age deficit. Local task-switching costs, on the other hand, showed a multiplicative complexity effect but no specific attention-related age deficits. Cueing or switch predictability did not affect age differences.

Keywords

task switching; aging; meta-analysis; executive control

It is well known that age-related differences exist in many cognitive tasks. Age-related declines have been noted for tasks such as simple and choice reaction times, working memory, episodic memory, tests of spatial and reasoning abilities, mental rotation, and visual search (for reviews, see, e.g., Kausler, 1991; Salthouse, 1991, 1996). The main challenge for cognitive aging research is to identify the probable causes of these deficits. Given the wide range of deficits, current theory favors explanations that focus on a limited number of very basic mechanisms.

Two families of theories currently dominate the field of cognitive aging. The first is the processing-speed hypothesis (Salthouse, 1991, 1996): A high processing rate is important for cognitive performance, and processing rate goes down with age. The second type of theory distinguishes between tasks that involve executive control processes, such as selecting information to be attended to or switching between different sources, and tasks in which these demands are negligible. Executive control processes that are believed to be age sensitive include inhibitory control (Hasher & Zacks, 1988), coordination ability (Mayr &

Kliegl, 1993; Mayr, Kliegl, & Krampe, 1996), and attention switching between tasks (Mayr, Spieler, & Kliegl, 2001).

This article evaluates the claim of age-relatedness for one aspect of executive control, namely the ability to switch between tasks. To that end, we conducted a quantitative literature review (see Verhaeghen & Cerella, 2002, for an earlier such analysis).

In the task-switching paradigm, participants perform a series of distinct simple tasks in succession, typically on the same type or set of stimuli. For instance, the participant may be shown a series of digits and instructed to make odd/even judgments on a particular subset of trials and small/large judgments on a different subset of trials. When the task performed on a given trial is different from the task performed on the immediately preceding trial (a switch trial), a cost is typically found; that is, participants are slower, less accurate, or both, than on trials in which the task repeats (a nonswitch trial).

Two types of costs are typically calculated. First, the response time (RT) difference between nonswitch trials in a condition in which only a single task is performed (i.e., a *pure* task block) is compared with that of a condition in which subjects alternate between two different tasks (i.e., a *mixed* block); this is referred to as the *global* switch cost. Global switch costs are thought to measure the set-up cost associated with maintaining and scheduling two mental task sets, as well as the added load associated with maintaining multiple task sets in working memory (e.g., Kray & Lindenberger, 2000). Second, the RT difference between switch and nonswitch trials within mixed blocks (i.e., switching on a trial-to-trial basis) is referred to as the *local* switch cost. Local switch costs are thought to reflect the executive processes required to deactivate the task set relevant on the previous trial and to activate the currently relevant task set (Monsell, 2003). Using structural equation modeling, Kray and Lindenberger (2000) confirmed that global and local switch costs are indeed distinct and domain-general aspects of cognitive control.

Our analytical framework of choice is graphical meta-analysis (e.g., Cerella, Poon, & Williams, 1980; Sliwinski & Hall, 1998). We compiled all relevant RT data from the literature to construct a related pair of scatter plots that expose (a) age effects within and across conditions and (b) complexity effects within and across age groups. The first type of plot is called a *Brinley function* (Brinley, 1965). It displays the average performance of older adults across the various levels and conditions of the collected data as a function of the average performance of younger adults across the same levels and conditions. Brinley functions have often been found to be linear or near-linear; the slope of the function gives the age-related slowing factor (Cerella, 1990). The second type of plot is called the *state trace* (Mayr, Kliegl, & Krampe, 1996; Verhaeghen, 2000). It displays the average performance of one age group over more complex levels and conditions (in the present case, task-switching conditions) as a function of the performance of the same age group over corresponding baseline levels and conditions (in the present case, pure-task blocks for global switch costs and nonswitch trials for local switch costs).

Several configurations of Brinley functions and state traces are possible. Verhaeghen, Steitz, Cerella, and Sliwinski (2003) offered a formal mathematical treatment of the Brinley and

state trace functions for younger and older adults under two cases: additive complexity effects and multiplicative complexity effects. We briefly summarize the mathematical development here. Most task-switching studies are based on models that describe task switching as a discrete, stage-like control operation that precedes stimulus identification and operates prior to task execution (De Jong, 2000; Meiran, 1996, 2000; Meiran & Gotler, 2001; Rogers & Monsell, 1995). This control process is added as an extra stage (or stages) to the processing stream. We have labeled this effect *additive complexity* because the increased demand will induce additive effects between the baseline and experimental conditions. The resulting state trace will be a line elevated above and parallel to the diagonal. The switch cost is given directly by the intercept value of the state trace (i.e., the distance from the diagonal). The general slowing axiom stipulates that the switch cost for older adults will be equal to the switch cost for younger adults times the age-related slowing constant (which is itself given by the slope of the Brinley function for the baseline task). This means that even under the general slowing hypothesis, the state trace for older adults will be elevated above and parallel to the state trace for younger adults; therefore, the results of state trace analysis alone are not conclusive to determine the presence of a specific age-related deficit. The Brinley function, however, will disambiguate the results with regard to age deficits. If two lines are present in the Brinley function, this implies that the additional additive demands of the task-switching requirement slow down the older adults by a larger amount than predicted by the central component in the single tasks.

Alternately, a task-switching manipulation may interfere with the central processing of a task, prolonging or inflating each step in the chain of baseline computations. We label this type of effect *multiplicative* because it will induce a multiplicative cost: Central processing latencies in the switching conditions will be a fixed ratio of central processing latencies in the single-task conditions (see Verhaeghen et al., 2003, for a mathematical treatment). The state trace will have a slope greater than unity; the size of the multiplicative effect is given directly by the slope of the state trace. Depending on whether the age-related task-switching deficit is greater than the age-related single-task deficit, the line for older adults will overlap the line for younger adults or diverge from it. The Brinley functions yield the same result as the state traces, that is, we will observe slopes larger than unity. Depending on whether the age-related task-switching deficit exceeds the central deficit or not, the Brinley functions for the two tasks will overlap or diverge.

The expectation, given the extant literature is that global task switching is age sensitive and local task switching is not (see, e.g., Kray & Lindenberger, 2000, and Mayr, 2001). The literature does not, however, give any indication as to what type of complexity effect to expect for these two task-switching measures. We note that global task-switching costs might be likened to dual-task costs in that both seem to originate from the requirement to actively maintain and schedule two mental tasks sets, and that local task-switching costs may be likened to tasks of selective attention in that both require the selection of specific task sets. In a previous dual-task meta-analysis (Verhaeghen et al., 2003), additive costs and age sensitivity in those costs were obtained, and we expect the same for global task switching. Previous meta-analyses (Verhaeghen & De Meersman, 1998a, 1998b) on

selective attention (Stroop and negative priming) have yielded multiplicative costs and no age deficits, and we expected the same for local task switching.

The focus of our analysis is on the description of age differences, not on general effects of different manipulations in task or stimulus material on task switching. Some of these effects, however, may interact with age differences and are therefore explored here. We included two potential moderating variables in our analysis. The first variable was whether a cue to switch was present or absent. Having to switch rapidly between task sets without the aid of external cues is thought to be highly demanding on internal action control. Therefore, cueing paradigms generally result in smaller switch costs (Kray, Li, & Lindenberger, 2002; Kray & Lindenberger, 2000). The second moderating variable was whether the sequence of tasks is predictable (i.e., participants are aware of a prespecified task sequence) or not (i.e., the task sequence is presented in a random fashion). Some previous research has suggested that paradigms employing unpredictable task sequences generally yield larger task-switching costs (Rogers & Monsell, 1995; but see Tornay & Milan, 2001).

Method

Sample of Studies

Studies were collected using the PsycINFO electronic database, through personal contacts, and by the ancestry approach. The search was concluded in December 2009. Studies were included if (a) the study contained a comparison between younger adults (college age) and older adults (mean age 60 or over) and (b) the dependent measure was latency. Additionally, within mixed blocks, latency for switch trials and nonswitch trials needed to be reported separately to allow for the correct calculation of local and/or global costs. Data from a total of 36 independent groups of subjects contained in 26 articles (starred in the References section) met these criteria. Thirty-four of these were included in the analysis of local costs; 23 were in the analysis of global costs. An Excel spreadsheet may be obtained by contacting Christina Wasylyshyn.

Procedure

Hierarchical linear modeling (HLM; Sliwinski & Hall, 1998; Verhaeghen et al., 2003) was used to analyze the latency data. Contrary to traditional pooled or aggregate regression procedures, regression parameter values obtained from HLM are derived using information both within and across studies. Two analyses were undertaken to graphically represent (a) task-switching effects within and across age groups (state trace analysis); and (b) age effects within and across task-switching conditions (Brinley analysis). For the state trace analysis, mean RT in task-switching conditions was regressed on mean RT in nonswitching conditions separately for younger and older adults. We then tested whether one line could describe the data or whether two lines (one for older adults and one for younger adults) were necessary to explain the relationship between pure- and mixed-task performance. For the Brinley analysis, mean RT of older adults was regressed on mean RT of younger adults. We again tested whether one or two lines (one for switching conditions, one for nonswitching) were necessary to explain the data.

Results

Figure 1A displays the state trace for global task switching (46 data points obtained from 23 independent subject groups). Note that only nonswitch trials were included in the mixed condition to make the comparison with pure-task performance as unambiguous as possible. Interaction terms were removed from the model if they were not significant. The resulting model led to two lines in the state trace that were parallel to the diagonal: one for older adults and one for younger adults. The slope relating mixed-task performance to pure-task performance was 0.98 ($SE = 0.25$; this value is not significantly different from 1). Fixing the slope to 1 did not significantly reduce fit ($p = .93$); the Age $\times$ Trial Type interaction was not significant ($p = .51$). After fixing the slope to 1 and removing the interaction term, we determined that the estimate for the intercept was 145.85 ms ($SE = 40.00$; the intercept was significantly larger than zero). The effect of age group on the intercept was 140.86 ms ($SE = 56.57$). This value was significantly larger than zero; therefore, the intercept for older adults was larger than that for younger adults. These results are consistent with an additive global switch cost and with an additive age-related deficit in the process or processes associated with the global task-switching cost. Residual plots inspected for heteroscedasticity revealed no systematic pattern, indicating that our model fit the data adequately. Next, we determined the extent to which our two potential moderator variables influenced the additive global task-switching cost. We found that additive effects did not differ between studies with cues and those without cues ($p = .42$), and between studies in which task sequences were predictable and studies in which sequences were not predictable ($p = .51$).

Figure 1B depicts the state trace for local task switching (68 data points obtained from 34 independent subject groups). After we removed the nonsignificant higher order interactions, the effect of age group on the intercept was not significant ($p = .60$). These two results indicate that age effects were absent in local task-switching costs. We obtained the following parameters: The intercept was -93.87 ms ($SE = 145.22$; the intercept was not significantly different from zero), and the slope relating switch trials in mixed-task performance to nonswitch trials in mixed-task performance was 1.43 ($SE = 0.15$). This slope was significantly larger than 1, indicating a multiplicative cost. The possible influences of the two potential moderator variables were also investigated; none of the effects reached statistical significance. Additive effects did not differ between studies with cues and those without cues ($p = .82$), and between studies in which task sequences were predictable and studies in which sequences were not predictable ($p = .39$).

Figure 1C displays the Brinley function for global task switching (46 data points from 23 independent subject groups). The analysis indicated the presence of two lines: one for pure tasks and one for mixed tasks. These lines were parallel, indicating additive age effects. After we removed nonsignificant higher order interactions, the resulting parameter estimates were the following: (a) the intercept for nonswitch trials in pure blocks = 93.81 ms ($SE = 65.48$; this intercept was not significantly different from zero), (b) the significant increase in intercept for nonswitch trials in mixed blocks = 102.00 ms ($SE = 39.68$; the intercept for nonswitch trials in mixed blocks was thus 195.81), and (c) the slope relating mixed-task performance to pure-task performance = 1.27 ($SE = 0.10$; this slope was different from 1). Thus, we obtained two lines: one for pure-task conditions, with an intercept of 93 ms and a

slope of 1.26, and one for mixed-task performance, parallel to the pure-task performance line but elevated 102 ms above it. This result indicates age sensitivity in the process or processes that underlie global task switching. As in the state-trace analysis, additive effects did not differ between studies with cues and those without cues ($p = .32$), and between studies in which task sequences were predictable or not predictable ($p = .77$).

Figure 1D depicts the latency Brinley function for local task switching (68 data points, denoting 34 independent groups). The results indicated that a single line sufficed to explain the data. After we removed nonsignificant higher order interactions from the model, the resulting parameter estimates were as follows: intercept = 103.55 ms ($SE = 123.83$; the intercept was not significantly different from zero) and slope = 1.47 ($SE = 0.14$; the slope was significantly larger than 1). Analysis of the influence of the moderator variables on the multiplicative local task switching effect yielded no significant effects. We found that additive effects did not differ between studies with cues and those without cues ($p = .07$), and between studies in which task sequences were predictable and studies in which sequences were not predictable ($p = .11$).

Discussion

We conducted a quantitative literature review on global and local task-switching costs. Multilevel modeling (Sliwinski & Hall, 1998) was used to conduct state trace and Brinley analyses. These analyses yielded two types of results: (a) whether a particular cost was of the additive or multiplicative type and (b) whether age-associated deficits were present.

With regard to the type of cost, the results were unambiguous. For global switch costs, the data showed an additive pattern, with the task-switching processes adding 141 ms on average to the pure tasks in younger adults. For local switch costs, the data demonstrated a multiplicative pattern, resulting in 43% slowing compared with nonswitch trials. These results can be placed in the broader context of our previous work. We have found that tasks of selective attention (i.e., Stroop and negative priming) yielded multiplicative effects (Verhaeghen & De Meersman, 1998a, 1998b); dual-task performance yielded additive effects (Verhaeghen et al., 2003). One similarity between dual tasking and global task switching is that both require the simultaneous activation and maintenance of two mental task sets; the costs of maintaining dual states of mind appear to be additive—the cognitive system appears to deal with this complication by means of an added stage. Local task switching resembles traditional tasks of selective attention in that both involve selection between two mental task sets that are already active. It is not surprising that the resulting costs are qualitatively similar in the two cases (i.e., multiplicative).

With regard to age differences, the results were equally unambiguous. First, global task switching was clearly age sensitive. In the state trace, the lines for younger and older adults separate out reliably, as do the lines for switch and nonswitch blocks in the Brinley function. Thus, the processing penalty associated with the additional stage(s) in global switching led to an increase in age differences over and beyond the slowing that was present in the baseline tasks. The age-related slowing factor in the baseline conditions (given by the slope of the Brinley function) was 1.27; the age-related slowing ratio in the global task-switching

cost (i.e., the old/young ratio of the average difference between global task nonswitching trials and pure-task trials) was 1.97, that is, $(145.85 + 140.86)/145.85$. This result goes clearly against any account that would explain age sensitivity of global task switching through a general slowing mechanism. We should point out that although a number of studies have shown that individual differences in cognitive speed explain a substantial portion of the age-related differences in global task switching (Cepeda, Kramer, & Gonzalez de Sather, 2001; Kray & Lindenberger, 2000; Salthouse, Fristoe, McGuthry, & Hambrick, 1998), these studies also have found that a significant portion of age differences in global task switching remains unaccounted for. Second, local task switching appears to be age constant, as indicated by the finding that one line described the data adequately in both the state trace and the Brinley function. Consequently, after taking general slowing into account, we found that older adults were as efficient as younger adults in switching between alternate task sets. These results square well with the existing literature, which concurs that there are large age differences in global switch costs and smaller or no age differences specific to local switch costs. However, some exceptions should be noted. Meiran, Gotler, and Perlman (2001) found that older adults show greater global and local costs than do younger adults. Kray et al. (2002) obtained larger age differences in local switch costs than in global switch costs. Mayr and Kliegl (2000) found that when episodic retrieval task demands were relatively low, there were negligible age differences for local and global switch costs.

Our findings point at deeper implications as well. Considering all of the meta-analyses mentioned here (the present analysis; Verhaeghen & De Meersman, 1998a, 1998b; and Verhaeghen et al., 2003), a pattern in the age outcomes becomes apparent. We conclude that there is no age-related deficit specific to processes of selective attention, at least not in the three task types considered, but we note that having to maintain two task sets does involve a deficit over and beyond the effects of general slowing. The deeper reason for this deficit might be situated in age-related differences in working memory, as mediated by frontal lobe functioning. Several researchers (Bopp & Verhaeghen, 2007; Kramer et al., 1999; Kray & Lindenberger, 2000) have stressed that impairments of older adults are strongly related to the organization of cognitive processing within working memory. Older adults can efficiently activate and deactivate the cognitive system to perform task switches (i.e., there are no age-related differences in local switch costs), but they are impaired when maintaining and coordinating two task sets in working memory. Even seemingly contradictory results might fit this pattern. For instance, Kray and Lindenberger (2000) originally found that global switch costs were significantly greater than local switch costs but later found the opposite results when they increased the number of potentially relevant task sets from two to four (Kray et al., 2002). In the latter case, the increased working memory demands might have caused an age deficit to emerge in a process that is normally age insensitive. An alternative view is that age sensitivity in global costs occurs when internal control settings must be updated, especially in the face of interference. Switching to a new task and updating one's mental task set are taxing and involve activating task-relevant information from long-term memory (Mayr, 2001). In either case, this pattern of switch costs has implications for the frontal lobe hypothesis of cognitive aging (e.g., West, 1996, 2000). Neural correlates of local and global switch costs have been distinguished in the prefrontal cortex (Braver, Reynolds, & Donaldson, 2003; Goffaux, Phillips, Sinai, & Pushkar, 2006), and marked age-

related patterns of activation for local and global switch costs have been exhibited (Jimura & Braver, 2010).

Some limitations to our conclusions should be addressed. First, the number of studies, although presumably spanning the whole of the relevant literature, is relatively modest, resulting in relatively low power. Second, our meta-analysis lumped together a rather heterogeneous group of studies. That being said, what also emerged from the moderator analyses is the prolific use of cued designs (only three of the studies included in this meta-analysis used noncue designs) and the abundant use of unpredictable task sequence designs (only nine of the studies included in this meta-analysis used predictable designs). Even though our moderator analyses suggests that age differences in the task-switching effect do not covary with different types or complexity levels within a particular task, more careful experimental analysis is clearly needed before we can accept this null hypothesis.

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Figure 1.

Meta-analytic state traces and Brinley functions, along with regression lines derived from hierarchical linear modeling of the data, for studies investigating local and global task switching; each of the data points plotted in the figures represents a single study. Two regression lines are needed for global switching in both state trace and the Brinley function, indicating that global task switching is age sensitive. A single regression line suffices to capture the data for local switching, indicating that this process is not age sensitive.