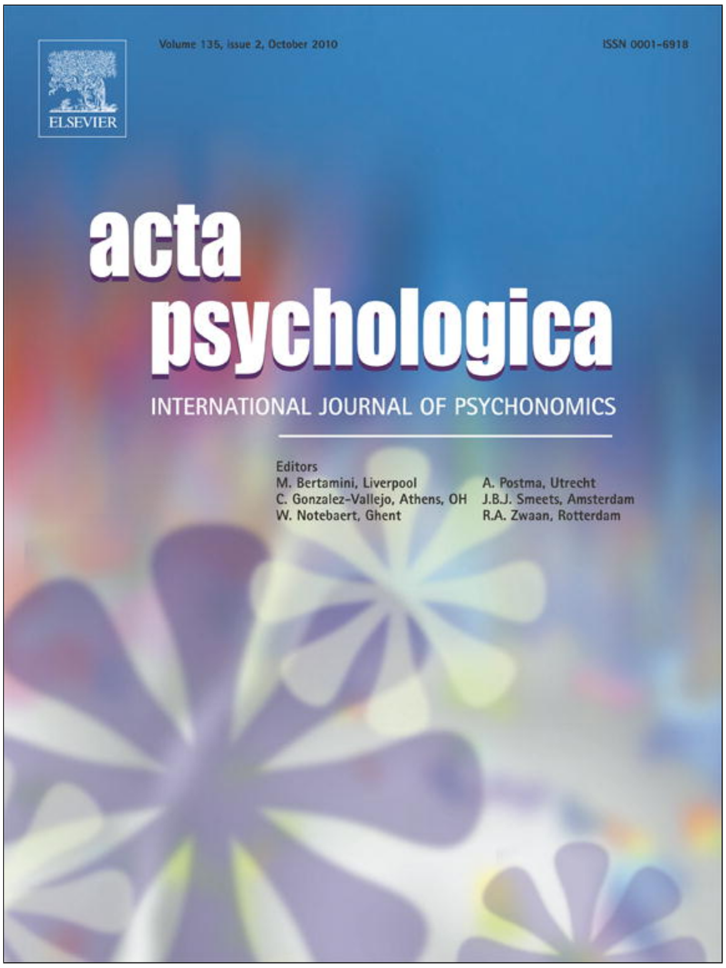
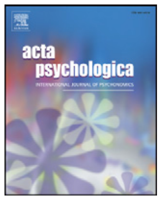

Volume 135, issue 2, October 2010
ISSN 0001-6918
ELSEVIER
acta
psychologica
INTERNATIONAL JOURNAL OF PSYCHONOMICS
Editors
M. Bertamini, Liverpool
C. Gonzalez-Vallejo, Athens, OH
W. Notebaert, Ghent
A. Postma, Utrecht
J.B.J. Smeets, Amsterdam
R.A. Zwaan, Rotterdam

Acta Psychologica 135 (2010) 140–149

Contents lists available at ScienceDirect

Acta Psychologica

journal homepage: www.elsevier.com/ locate/actpsy



Age differences in switching the relevant stimulus dimensions in a speeded same–different judgment paradigm

Shulan Hsieh [a,*], Mengyao Wu [b]

[a] Department of Psychology and Institute of Cognitive Science, National Cheng Kung University, Tainan, Taiwan
[b] Department of Psychology, National Chung Cheng University, Chia-Yi, Taiwan

A R T I C L E I N F O

Article history:
Received 9 January 2010
Received in revised form 27 May 2010
Accepted 30 May 2010

PsycINFO classification:
2860

Keywords:
Same–different judgment
Perceptual dimension
Conceptual dimension
Preparatory interval
Switch cost
Mixture model

A B S T R A C T

The present study employed a same–different judgment task-switching paradigm to re-examine the effects of age on switch costs. We manipulated perceptual and conceptual dimensions to serve as the criteria for making a same–different judgment. We also manipulated a short versus long cue-stimulus interval, while keeping the response–stimulus interval constant in order to examine whether older adults can benefit from longer preparatory intervals. The results indicate that older adults exhibited larger switch costs. In contrast to this impairment, older adults maintained the ability to prepare for an upcoming task switch. Nevertheless, even with a long preparatory interval, older adults still exhibited larger switch costs than younger adults. A more detailed analysis using a mixture model technique suggests that older adults' elevated residual costs in performing perceptual-judgment switches might be attributable to an increased probabilistic failure to complete advance preparation, whereas older adults' elevated residual costs in performing conceptual-judgment switches might be attributable to an intrinsic limitation in their ability to attain a complete task-set reconfiguration during a preparatory interval.

1. Introduction

As people age, many cognitive functions may deteriorate, including perceptual processing speed (Madden, 2001; Salthouse, 1994, 1996), working memory capacity (Grady, & Craik, 2000; Salthouse, 1994; West, 1996), inhibitory processing (Hasher, & Zacks, 1988; Kramer, Humphrey, Larish, & Logan, 1994), and cognitive flexibility (Kramer, Hahn, & Gopher, 1999; Mayr, 2001). In addition, some evidence suggests that age-related decline occurs specifically in top-down cognitive control, a phenomenon hypothesized to be the result of an age-related decline in prefrontal cortex functioning (Braver et al., 2001; Hartley, 1993; Hasher, & Zacks, 1988; Moscovitch, & Winocur, 1992; Phillips, & Henry, 2008; West, 1996). In line with this evidence, Lien, Ruthruff, and Kuhns (2008) proposed an “internal control deficit” hypothesis to explain the finding that older adults have weaker top-down internal control over task settings when compared to younger adults. Among the various cognitive control tasks, the task-switching paradigm has received much attention over the past two decades and has become a popular tool for the investigation of the effects of aging on cognitive control. This research trend is gaining credibility because task switching appears to be relevant for adaptive behavior; thus, examining how such an adaptive behavior may be affected by old age is highly important. Human beings have to organize their minds and bodies in a particular way–i.e., adopting an appropriate “task-set”–to perform tasks in everyday situations, and very often, they need to rapidly shift from one mental set to another to perform various tasks in a dynamic environment. Based on evidence that suggests that aging is associated with a decline in frontal lobe function, we might anticipate that the processes supporting dynamic adjustments to a changing environment would be disrupted in older adults. Unfortunately, conclusions as to whether there is an age-related difference in task-switching efficacy have thus far been equivocal. The controversy may lie in the fact that the switch cost by no means represents a unitary process, but rather involves several subcomponent processes associated with the type of task-switching paradigms in use. Furthermore, different task-switching settings may demand a different degree of control demands. It is possible that older adults are less efficient only for some subcomponent processes but not for others, and that older adults may show deficits in task switching with high but not low control-demand settings (e.g., Mayr, 2001). To elucidate the effects of age on task-switching efficacy, the present study supplemented empirical data with a same–different judgment task-switching paradigm, which has been hypothesized to be higher in control demand and focuses on some subcomponent processes for which age effects remain controversial.

* Corresponding author. Department of Psychology and Institute of Cognitive Science, College of Social Sciences, National Cheng Kung University, 1 University Road, Tainan 70101, Taiwan. Tel.: +886 6 2008703.
E-mail address: psyhsl@mail.ncku.edu.tw (S. Hsieh).

0001-6918/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.actpsy.2010.05.010

1.1. Taxonomy in task-switching paradigms

In the laboratory, researchers have designed various versions of task-switching paradigms to understand the mechanisms involved in the ability to dynamically adapt to changes in task contexts. In one of the earliest task-switching paradigms developed by Jersild (1927; see also Allport, Styles, & Hsieh, 1994; Spector, & Biederman, 1976), the tasks were presented in a predictable order, either repeatedly throughout a block (i.e., pure [single]-task block; e.g., AAAA…; BBBB…) or in a simple alternating fashion (mixed-task block; e.g., ABAB…). Performance costs were measured by subtracting the average reaction time (RT) in pure-task blocks from those in mixed-task blocks. Thus, RT differences contained both generic *switch costs* and *mixing costs*. For example, the mixed-task blocks may impose greater working memory load (remembering two tasks) and might promote greater effort and arousal. Rogers and Monsell (1995) tried to obtain generic switch costs by developing an alternating-runs paradigm (e.g., AABB… or AAAABBBB…) in which they mixed both switch and non-switch trials within the same blocks of trials. They computed switch costs by subtracting the average RT of the non-switch trials (i.e., the second trial of the AA and BB sequence) from that of the corresponding switch trials (i.e., the second trial of the AB and BA sequence). As such, switch costs (also known as *local switch costs*: the RT differences between switch and non-switch trials in the same mixed-task block) can be measured accurately, uncontaminated by unwanted differences between conditions in memory load, effort, arousal, etc. (also known as *mixing costs*[1]: the RT differences between trials in the pure-task block and non-switch trials in the mixed-task block).

Researchers who emphasize examining the preparatory component process in task-switching paradigms recommend using a task-cueing paradigm (e.g., Cue A–Task A–Cue B–Task B–Cue B–Task B…) because the experimenter has little control over the point in time at which an endogenous act of control begins in the alternating-runs paradigm (Meiran, 1996). For example, participants might perform a repeated task while preparing a task switch and perform a switched task while preparing for a task repetition. The task-cueing paradigm enables one to independently manipulate the cue-stimulus interval (allowing active preparation) and the response-cue interval (allowing passive dissipation). Increasing the interval between the response to the previous trial (trial $n-1$) and the cue onset of the current trial (trial n)–i.e., response-cue interval (RCI)–has been shown to result in a reduction in switch costs. This finding can be attributed to the passive dissipation of the task adopted in the previous trial, because during this period participants are unlikely to prepare for unknown forthcoming tasks (see Meiran, Chorev, & Sapir, 2000 for empirical support). On the other hand, increasing the interval between the cue onset and the stimulus onset–i.e., cue-stimulus interval (CSI)–has been found to result in a reduction in switch costs, which reflects the preparatory component since the instructional cue has been given (Meiran, 1996; Meiran et al., 2000).

However, many studies have found that even by increasing CSI to a very long interval (e.g., >1000 ms), residual switch costs remain (Allport et al., 1994; Meiran, 1996; Rogers, & Monsell, 1995). In an attempt to explain these residual costs, de Jong (2000) proposed the failure-to-engage (FTE) theory. According to FTE theory, residual costs are attributable to intermittent failures to engage in advanced preparation, and not to a fundamental inability to attain a complete reconfiguration for a task switch during the preparatory interval. That is, given a long preparation interval and the intention to prepare, participants succeed on only a portion of the trials in completing the preparation before the stimulus onset (fully prepared trials). Furthermore, they fail to engage in preparation before the stimulus onset on other trials (unprepared trials). As such, performance on switch trials with a long preparatory interval with advance preparation should be similar to that of non-switch trials, whereas performance on switch trials with a long preparatory interval without advance preparation should resemble that of switch trials with a short preparatory interval that provides little time for advance preparation.

Another major theory concerning residual switch costs is the additional process (AP) hypothesis proposed by Rogers and Monsell (1995). They posited that the duration of an “exogenous” component of task-set reconfiguration, which cannot be completed until the presence of the stimulus, is responsible for the residual cost. According to AP theory, residual switch costs are due to intrinsic limitations on the completeness of task-set reconfiguration for all switch trials in advance of the stimulus presentation. Conversely, according to FTE theory, residual switch costs are only due to a subset of switch trials that failed to be fully prepared in advance. de Jong (2000) reconciled these two views and developed a mixture model for evaluating the proportional contributions of both FTE and AP accounts of the residual switch cost (see Appendix).

In contrast to FTE and AP, some researchers have argued that RT switch costs measured with task-cueing paradigms may not necessarily reflect an endogenous control process of task-set reconfiguration, but instead simply a cue repetition benefit. This is because in a conventional task-cueing paradigm, there is only one cue per task; thus, a task switch is always confounded with a cue switch (Logan, & Bundesen, 2003; Schneider, & Logan, 2005). However, even though non-control properties may indeed contribute to RT switch costs, recent studies (both behavioral and neuroimaging) have shown that cue processing is not solely perception- and memory-based. In fact, processing task cues in task switching during CSI has been demonstrated to be sensitive to control demands, and therefore, to involve cognitive control (e.g., Jost, Mayr, & Rösler, 2008; Mayr, & Kliegl, 2003; Monsell, & Mizon, 2006; Nicholson, Karayanidis, Bumak, Poboka, & Michie, 2006; Ruge et al., 2005). The present study does not exclude one theory over the other, but rather adopts a view that a task-cueing paradigm can nevertheless measure some task-set reconfiguration processes, if not all.

1.2. Aging in task-switching component processes

Given the existence of several subcomponent processes one can derive from various task-switching paradigms, it is interesting and theoretically important to review the literature on task switching and aging, along with these subcomponent processes.

1.2.1. Mixing costs

The literature on task switching and aging so far has provided a consensus regarding age-related differences in mixing costs (e.g., Hartley, Kieley, & Slabach, 1990; Kramer et al., 1999; Kray, & Lindenberger, 2000; Salthouse, Fristoe, McGuthry, & Hambrick, 1998). The difficulty reflected by increasing mixing costs for older adults has been primarily attributed to their inefficiency in maintaining multiple task sets in working memory (Kramer et al., 1999; Kray, Eber, & Lindenberger, 2004; Kray, & Lindenberger, 2000).

1.2.2. Local switch costs

On the other hand, the literature on age-related differences in local switch costs remains controversial (e.g., Allen, Ruthruff, & Lien, 2007). While some researchers report significant age-related differences in switch costs (e.g., de Jong, 2001; DiGirolamo et al., 2001; Meiran, Gotler, & Perlman, 2001), others have found moderate or even no age-related differences (e.g., Hartley et al., 1990; Kramer et al., 1999; Kray,

[1] Some researchers defined mixing costs as the RT differences between trials in the pure-task block and non-switch trials in the mixed-task block; whereas others defined them as the RT differences between the pure-task and mixed-task blocks (i.e., alternating-run mixed-task blocks), which include both non-switch and switch trials (e.g., Hartley, Kieley, & Slabach, 1990; Kramer et al., 1999; Kray, & Lindenberger, 2000; Salthouse, Fristoe, McGuthry, & Hambrick, 1998).

& Lindenberger, 2000; Lien et al., 2008; Salthouse et al., 1998; Verhaeghen, Cerella, Bopp, & Basak, 2005). Researchers have speculated that such discrepancies may be related to the degree of control demands for different task-switching settings. For example, Lien et al. (2008) suspected that their null finding on disproportional switch costs for older adults might be due to their use of distinct stimulus dimensions for each of the two tasks. Mayr (2001) also indicated that age-related differences in switch costs might be associated with stimulus ambiguity (i.e., stimulus bivalence) or response-set overlap between the two shifted tasks.

1.2.3. Preparatory component

Previous research has reported that older adults can utilize longer preparatory intervals to prepare for upcoming task switches (e.g., Hartley et al., 1990; Kramer et al., 1999; Kray, & Lindenberger, 2000; Meiran et al., 2001). In these task-switching studies, increasing the CSI significantly reduced switch costs and the rate at which preparation reduced switch costs was similar for younger and older adults. Nevertheless, some studies in other research fields, such as the visual search domain, have further differentiated situations in which, under specific cueing conditions, older adults may exhibit intact preparatory component processes. For example, researchers have shown that when selective attention in a visual search paradigm relies on "bottom-up" processes, older adults can use these local changes in information to improve their search performance just as efficiently as younger adults. On the other hand, when the attentional guidance relies heavily on "top-down" processes, older adults are less efficient than younger adults in using the relevant information to improve their performance (Folk, & Lincourt, 1996; Madden, Whiting, Spaniol, & Bucur, 2005). Given these findings, it is possible that the ability to prepare for a task switch can still be maintained for older adults when preparation in advance becomes more limited.

1.2.4. Task-set dissipation and residual components

Apart from the preparatory component, switch costs may consist of other subcomponents, such as task-set dissipation and residual components. Meiran et al. (2001) observed a modest age effect on the rate of task-set dissipation (Exp. 3) by increasing the length of RCI (ranging from 132 to 3032 ms) while keeping the CSI constant and short (117 ms). On the other hand, age-related differences in the residual component remain controversial. Some studies have reported minimal or insignificant residual switch costs (e.g., Kramer et al., 1999; Kray, & Lindenberger, 2000; Lien et al., 2008), whereas others have reported large residual switch costs (e.g., de Jong, 2001; Mayr, & Liebscher, 2001; Meiran et al., 2001).

1.3. Objectives of the present study

To summarize, our review of the literature suggests that except for mixing costs and task-set dissipation, the effects of age on other subcomponent processes of task switching, such as local, preparatory, and residual switch costs, is still a matter of dispute. Therefore, the present study set out to provide more empirical data to elucidate the effects of age on task switching.

The primary objective of this study was to clarify whether age-related differences in local switch costs occur only when the control demand for a task switch is sufficiently high. To achieve this goal, we adopted a so-called "same–different judgment" task-switching paradigm (Meiran, & Marciano, 2002). The same–different judgment task requires participants to determine whether two simultaneously presented stimuli are the "same" or "different" with respect to the relevant dimension, regardless of differences in other (irrelevant) dimensions (Santee, & Egeth, 1980). Task switching in the same–different judgment task refers to situations in which participants switched between classifying sameness according to either of two different relevant dimensions (Meiran, & Marciano, 2002). This paradigm demonstrated not only that redirecting selective attention in advance becomes more difficult, but also that irrelevant stimulus dimensions interfere with the relevant dimension to a larger degree than the classifying task-setting (e.g., Meiran, & Marciano, 2002; Santee, & Egeth, 1980). To our knowledge, no one has yet employed this paradigm to examine the effects of age on task switching. In the present study, using the same–different judgment task-switching paradigm, we expect to observe disproportional slowing on switch trials, resulting in larger switch costs for older adults, based on the internal control deficit hypothesis set out by Lien et al. (2008).

Moreover, both perceptual dimensions (i.e., color or form) and semantic/conceptual dimensions (i.e., numerical magnitude: more/less; or parity: odd/even) were manipulated in the present study to serve as the relevant dimension for making same–different judgments. Santee and Egeth (1980) and Meiran and Marciano (2002) studies investigated only perceptual dimensions such as shape, size, shading, and fill (but see Meiran et al., 2000 for other manipulations, such as task-rule shifts and response-mapping shifts); thus, it remained an open question as to whether age-related differences on switch costs can be generalized to other types of same–different dimension judgments, such as parity or magnitude as well as whether the factor of judgment-dimension type interacts with age effects on local switch costs (see Lien et al., 2008 for a similar comment).

The second objective was to clarify whether older adults could maintain their ability to prepare for a task switch in advance, even under a task-switch setting in which advanced preparation in selective attention is limited, such as in the present same–different judgment paradigm (e.g., Meiran, & Marciano, 2002). This examination would help us to extend the previous findings that older adults kept their ability for advanced preparation intact during a task switch. In the present study, we did not examine the age effect on task-set dissipation, but in the preparatory component: we manipulated short (i.e., 200 ms) and long (1000 ms) intervals, while keeping constant the influence of the task-set dissipation for all trials (i.e., the RSI was kept constant at 2200 ms). This manipulation allowed us to observe the preparatory process in isolation from the effect of passive decay (see Meiran, 1996).

The final major objective was to investigate whether age-related differences in residual switch costs might be elevated in the current same–different judgment task-switching paradigms, in which advance preparation has been shown to be limited (e.g., Meiran, & Marciano, 2002). Moreover, given the two contending accounts of residual switch costs, FTE and AP, the present study would further examine how age-related differences in residual switch costs, if found, could be accounted for by pure FTE, pure AP, or a combination of both theories, by fitting the RT distribution to the generalized mixture model developed by de Jong (2000). It is also interesting to examine whether an age-related increase in residual switch costs is differentially attributable to different theoretical accounts (FTE vs. AP) for different types of judgment-dimension switches.

2. Materials and methods

2.1. Participants

We recruited 32 young adults (16 female; age range: 18–28 yr, $M = 20.68 \pm 2.24$; years of education: $M = 14.53 \pm 1.52$) from the National Chung Cheng University located in Chia-Yi County, and the National Cheng Kung University located in Tainan City. Participants received credit toward an introductory psychology course. Thirty-two older adults (age range: 60–74 yr, $M = 65.66 \pm 3.32$; years of education: $M = 13.94 \pm 1.92$) were recruited from the same local area and were paid NT$1000 (US$30). There was no significant difference in education level between the younger and older groups ($t(62) = 1.37$, $p = .18$). All participants were right-handed; free of cardiovascular, neurological, and psychological disorders; and had self-reported normal or corrected-

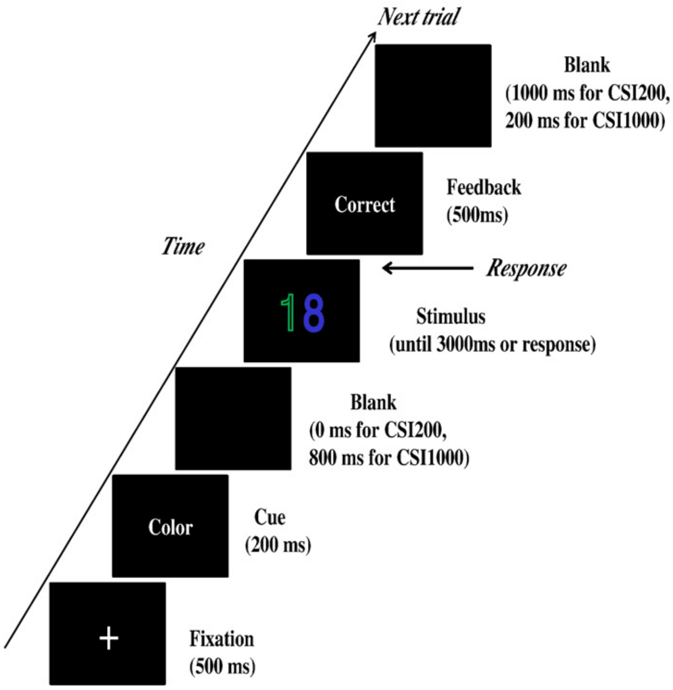


Fig. 1. An example of the time course of stimulus presentation. In this example, the stimulus (a pair of two digits drawn in different forms: full vs. empty and different colors: green vs. blue) is to be judged as *different* according to the dimensional cue, "color" (perceptual dimension).

to-normal vision. The experiment was conducted with the consent of each participant.

The Beck Depression Inventory (BDI-II) screened all participants for depression (Beck, Steer, & Brown, 1996; screening criteria: 0–13: normal; 14–19: mild depression; 20–28: moderate depression; 29–63: severe depression). The Mini-Mental State Examination (MMSE) screened all participants for dementia (Folstein, Folstein, & McHugh, 1975; screening criteria: 25–30: normal; 21–24: mild dementia; 14–20: moderate dementia; ≤13: severe dementia).[2] The mean BDI-II score was 5.03 ± 4.15 for young adults and 5.06 ± 3.95 for older adults (young vs. older: $t(62) = .03$, $p > .90$). The mean MMSE score was 29.81 ± .64 for young adults and 29.66 ± .70 for older adults (young vs. older: $t(62) = .93$, $p > .20$).

2.2. Apparatus and stimuli

A 17-in. monitor presented stimuli. E-Prime software (Psychology Software Tools, Inc., Pittsburgh, PA) generated stimuli on an IBM-PC computer with a Pentium 4 processor. Participants sat approximately 70 cm from the computer screen. Each stimulus (luminance: 120 cd/cm^2) display comprised a pair of Arabic digits subtended 1.23° horizontally and .82° vertically, presented in 20-point Datum font with full or empty form, and drawn in either blue (R: 0, G: 0, B: 255) or green (R: 0, G: 255, B: 0) color on a black background (luminance: 0 cd/cm^2; R: 0, G: 0, B: 0). The color and form of each digit was randomly and orthogonally assigned. The two digits displayed were adjacent to each other, and were independently and randomly selected from digits "1"–"9", excluding "5", with the constraint that no identical digits would be selected in the same display and none of the digits in consecutive displays was identical (see Fig. 1).

The two digits displayed varied independently along four dimensions (two perceptual dimensions: color and form; and two conceptual dimensions: parity and magnitude). Each digit was blue or green, full or empty, odd or even, and larger or smaller than 5. The two digits were to be judged the *same* if they were the same with respect to the task-relevant stimulus dimension (e.g., if the task-relevant dimension was color and both digits were the same color), regardless of whether they differed along any of the other three irrelevant dimensions (e.g., form, parity, magnitude). Accordingly, for each same or different judgment on the relevant dimension, there could be 0, 1, 2, or 3 competing (incongruent) responses afforded by the irrelevant dimensions. All pairs of digits were prepared for all possible pairings of *same* and *different* matches. For each of the different pairs, two displays were constructed with the positions of two digits reversed, so that the pairs were counterbalanced across positions.

2.3. Design and procedure

Participants were instructed to indicate whether two visually presented digits were the *same* or *different* based on a single task-relevant dimension (color, form, parity, or magnitude), regardless of whether the other three task-irrelevant dimensions were the same or different, by pressing one of two response keys as quickly as possible. There were four kinds of same–different judgment tasks: (1) Are the two digits in a pair the same (press the left-most button on the serial response box) or different (press the right-most button on the serial response box) in color? (2) Are the two digits in a pair the same or different in form? (3) Are the two digits the same or different in parity (odd/even)? and (4) Are the two digits the same or different in magnitude (>/<5)? The same-different response mappings were counterbalanced across participants. The four same–different judgment tasks were randomly and equally intermixed in a block. Each task was indicated by a verbal task cue, with the equivalents of color, form, parity and magnitude presented prior to each stimulus display. If the current trial required the same task-relevant dimension as the previous trial to make a same–different judgment, it was classified as a "repeat" trial; if the current trial required a different task-relevant dimension from the previous trial to make a same–different judgment, it was classified as a "switch" trial. The proportion of repeat and switch trials was about 50% each per block. Given that there were two perceptual and two conceptual dimensions in each, switch trials would involve either shifting within the two perceptual dimensions consecutively (e.g., color ↔ form; about 1/3 of switch trials), within the two conceptual dimensions consecutively (e.g., parity ↔ magnitude; about 1/3 of switch trials), or between one perceptual and one conceptual dimension (e.g., color ↔ parity; color ↔ magnitude; form ↔ parity; form ↔ magnitude; about 2/3 of trials).

Each trial started with a fixation cross for 500 ms, followed by a verbal task cue of 200 ms. After a CSI of 200 ms or 1000 ms, the stimulus display appeared (for the 200 ms CSI condition, the stimulus display appeared immediately following the offset of the cue; for 1000 ms CSI, the stimulus display appeared 800 ms following the offset of the cue) and remained on the screen until a response was given or until 3000 ms had elapsed, if no response was registered. Feedback ("correct" or "incorrect" of 500 ms duration) was given immediately following a response. Following feedback, a blank interval of 1000 ms (for the 200 ms CSI condition) or 200 ms (for the 1000-ms CSI condition) appeared before the next trial. Accordingly, each trial had a total RSI of 2200 ms (see Fig. 1).

The formal experiment consisted of 16 formal blocks (8 blocks for the 200 ms CSI conditions and 8 blocks for the 1000 ms CSI conditions). There were 97 trials per block, resulting in 1552 total trials for each participant (the first trial of each block was excluded from analysis). The order of the two lengths of CSI was counterbalanced across participants. Before the formal experiment, there was

[2] The main reason why we screened participants particularly for depression and dementia is because there is high prevalence rate for both disorders in old population, and both disorders are sensitive to general cognitive ability.

a practice session consisting of 48–96 trials, using a variety of trial conditions, so that participants would be familiar with the procedure.

3. Results

The first trial in a block and trials preceded by errors were excluded from all analyses. Trials in which the RT was exceedingly long (>3000 ms, considered as outliers) were analyzed for accuracy, but not for RT (<1%).

3.1. Reaction time (RT) data

3.1.1. Preliminary RT analysis: The effect of domain-switch type (within- vs. between-domain switch) on RT switch costs

In the current design, given that switch trials may involve shifting from one perceptual dimension to another (e.g., color → form or form → color), from one conceptual dimension to another (e.g., parity → magnitude or magnitude → parity), or from a perceptual dimension to a conceptual dimension or vice versa, it is worth examining whether there is a difference in the switch costs incurred among the various types of domain-switching. We conducted a four-way analysis of variance (ANOVA) on switch cost (RT(switch–non-switch/repeat))—with one between-subject factor of age (younger vs. older) and three within-subject factors: trial n's same–different judgment-dimension type (perceptual vs. conceptual dimension), domain-switch type from previous trial (trial $n-1$) to the current trial (trial n; within- vs. between-domain switch), and cue-stimulus interval (CSI; short vs. long). Results indicate that with the exception of the main effects of group ($F(1, 62) = 22.39$, $p < .001$), CSI ($F(1, 62) = 149.60$, $p < .001$) and trial n's same–different judgment-dimension type ($F(1, 62) = 6.85$, $p < .05$), all other effects were non-significant. This finding demonstrates that the effect of within- versus between-domain-switch type did not modulate switch costs. Therefore, future statistical analyses were collapsed across domain-switch type.

3.1.2. Formal RT analysis

Fig. 2A depicts mean RTs separately for age group, the current trial's (trial n) same–different judgment-dimension type, and task transition as a function of CSI.

We conducted a four-way analysis of variance (ANOVA), with a between-subject factor of age and three within-subject factors: trial n's same–different judgment-dimension type, CSI, and task transition. The results showed that responses were slower for older adults than for younger adults, $F(1, 62) = 73.18$, $p < .0001$; responses for same–different judgments based on conceptual dimensions were slower than those based on perceptual dimensions, $F(1, 62) = 152.25$, $p < .0001$; responses for the 200 ms CSI were slower than those for the 1000 ms CSI, $F(1, 62) = 278.57$, $p < .0001$; and responses for switch trials were slower than those for repeat trials, $F(1, 62) = 197.01$, $p < .0001$.

There were significant two-way interactions of age group and CSI, $F(1, 62) = 25.75$, $p < .0001$, age group and task transition, $F(1, 62) = 36.28$, $p < .0001$, and CSI and task transition, $F(1, 62) = 106.57$, $p < .0001$. There were also significant three-way interactions of age group, CSI, and task transition, $F(1, 62) = 19.35$, $p < .0001$, and of age group, CSI, and judgment-dimension type, $F(1, 62) = 8.45$, $p < .01$. All the other interactions were non-significant.

Post-hoc simple interaction effect tests on the three-way interaction of age group, CSI, and task transition indicated that regardless of CSI, both groups showed significant switch costs (200 ms CSI: older: 168 ms, $F(1, 124) = 305.74$, $p < .001$; younger: 66 ms, $F(1, 124) = 49.04$, $p < .001$; 1000 ms CSI: older: 69 ms, $F(1, 124) = 50.47$, $p < .01$; younger: 27 ms, $F(1, 124) = 7.97$, $p < .01$)), with older adults exhibiting larger switch costs than younger adults (200 ms CSI: $t(62) = 7.01$, $p < .001$; 1000 ms CSI: $t(62) = 3.55$, $p < .01$). In addition, older adults showed a larger reduction in switch costs from 200 ms CSI to 1000 ms CSI (mean switch cost differences between 1000 ms CSI and 200 ms CSI conditions: 99.56 ms) than younger adults (40.07 ms) (older vs. younger: $t(62) = 4.59$, $p < .0001$).

Post-hoc simple interaction effect tests on another three-way interaction effect of age, CSI, and judgment-dimension type indicated that regardless of judgment-dimension type, older adults showed a larger overall performance benefit than younger adults due to a longer preparatory interval (i.e., mean RT differences–collapsed over switch and non-switch trials–between 1000 ms CSI and 200 ms CSI conditions; perceptual dimensions: older: 145.75 ms, $F(1, 124) = 181.78$, $p < .001$; younger: 94.86 ms, $F(1, 124) = 76.99$, $p < .001$; older vs. younger: $t(62) = 3.55$, $p < .0001$; conceptual dimensions: older: 154.59 ms, $F(1, 124) = 204.46$, $p < .001$; younger: 65.42 ms, $F(1, 124) = 36.62$, $p < .001$; older vs. younger: $t(62) = 5.87$, $p < .0001$).

3.1.3. Log-transformed RT analyses

To clarify if larger switch costs and a larger reduction in switch costs from 200 ms to 1000 ms CSI found in older adults were due to general slowing, all RTs underwent logarithmic transformation (log-RT) before being re-submitted to ANOVA. The results of a new four-way ANOVA on log-RTs showed the same pattern as those on raw RTs reported above. This was especially true of the three-way interaction effect of age group, CSI, and task transition (which remained significant, $F(1, 62) = 4.54$, $p < .05$), as well as the following post-hoc analyses which likewise indicated that older adults exhibited larger switch costs than younger adults, and older adults showed a larger

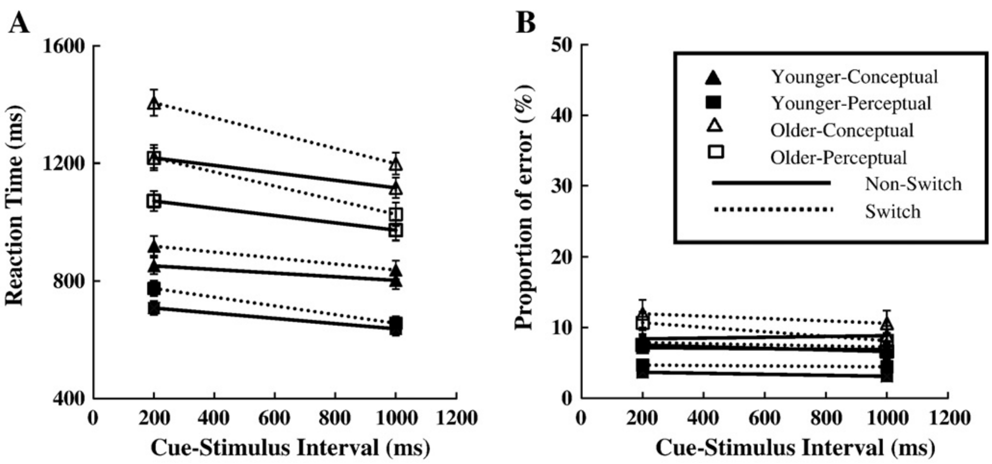


Fig. 2. (A) Mean correct RTs and (B) proportion of errors (PE) as a function of cue-stimulus interval (200-ms and 1000-ms CSI) for task transition (switch vs. non-switch), same–different judgment-dimension type (perceptual vs. conceptual), and age group (younger vs. older).

reduction in switch costs from 200 ms to 1000 ms CSI than younger adults (older vs. younger: $t(62) = 2.42$, $p < .05$).

3.1.4. Cumulative distributed function (CDF) and the best fits of the mixture model

A more detailed RT analysis using the mixture modeling technique developed by de Jong (2000) was carried out to delineate how FTE and/or AP theories might account for age differences in residual switch costs (i.e., switch costs at 1000 ms CSI) by estimating two free parameters (α and δ, see Appendix) in the mixture model formula to optimize the fit.

Fig. 3 shows the cumulative distribution functions for RTs in the three conditions for younger and older adults: non-switch trials with a long preparatory interval (1000 ms CSI), switch trials with a short preparatory interval (200 ms CSI), switch trials with a long preparatory interval (1000 ms CSI), and the best fits of the RT distribution function for switch trials with a long preparatory interval (as produced by the mixture model). As Fig. 3 indicates, the mixture model produced an excellent fit for both younger and older adults. Average estimated probabilities of *failures to engage* in advanced preparation (i.e., a $1 - \alpha$ parameter in the mixture model) for younger adults were .02 on perceptual-judgment

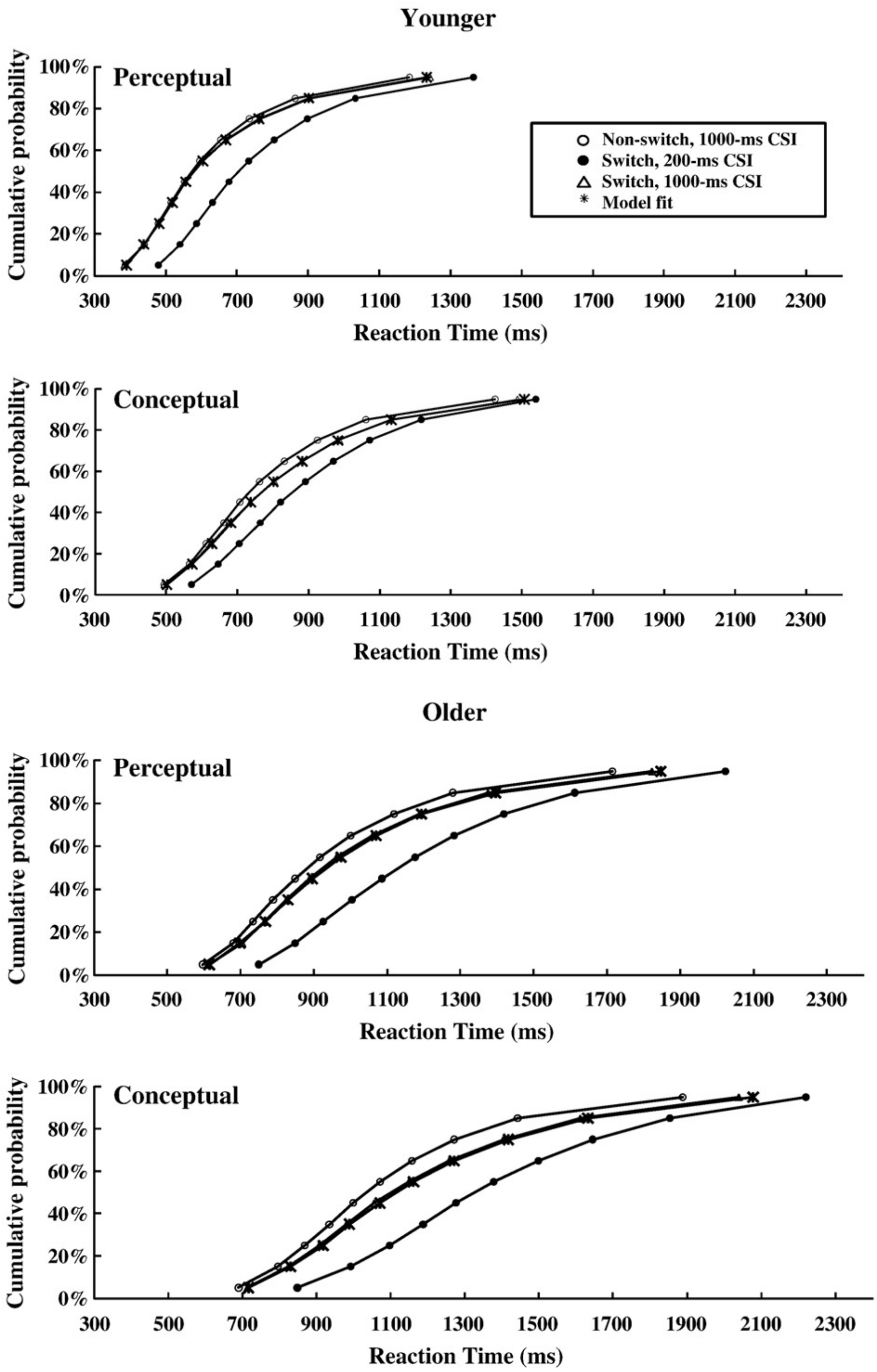


Fig. 3. Vincentised cumulative distribution functions of RTs for younger and older adults in the three conditions: non-switch trials with a long preparatory interval (1000-ms CSI), switch trials with a short preparatory interval (200-ms CSI), switch trials with a long preparatory interval (1000-ms CSI), and the best fits of the RT distribution function for switch trials with a long preparatory interval, as produced by the mixture model.

switches and .15 on conceptual-judgment switches; for older adults, these probabilities were .20 on perceptual-judgment switches and .21 on conceptual-judgment switches. A 2 (age group)×2 (judgment-dimension type) ANOVA for α values showed significant main effects of group ($F(1, 62)=16.07$, $p<.001$), and of judgment-dimension type ($F(1, 62)=6.67$, $p<.05$), as well as a significant interaction of age and judgment-dimension type ($F(1, 62)=4.79$, $p<.05$). Post-hoc simple effect tests revealed that the age effect reflected on α values was significant only on perceptual-judgment switches ($p<.05$), but not on conceptual-judgment switches ($p=.78$). Conversely, average estimated durations (i.e., δ parameter in the mixture model) of the exogenous component of the AP theory for younger adults were a non-significant −1 ms on perceptual-judgment switches and a non-significant −3 ms on conceptual-judgment switches; for older adults, estimated durations were a non-significant 14 ms on perceptual-judgment switches, but a significant 25 ms ($t(31)=3.46$, $p<.05$) on conceptual-judgment switches.

3.2. Error data (proportion of error, PE)

Fig. 2B depicts mean error rates (PEs) separately for age group, trial *n*'s same–different judgment-dimension type, and task transition as a function of CSI. A four-way analysis of variance (ANOVA) was conducted, with a between-subject factor of age and three within-subject factors: trial *n*'s same–different judgment-dimension type, CSI, and task transition. The results indicate that older adults committed more errors than younger adults ($F(1, 62)=6.76$, $p<.05$), same–different judgments based on conceptual dimensions invited more errors than those based on perceptual dimensions ($F(1, 62)=16.83$, $p<.001$); responses in 200 ms CSI were associated with more errors than those in 1000 ms CSI ($F(1, 62)=14.70$, $p<.001$); and responses for switch trials were associated with more errors than those for repeat trials ($F(1, 62)=27.69$, $p<.0001$). However, except for a significant interaction of age group and task transition ($F(1, 62)=6.56$, $p<.05$), suggesting that older adults committed more errors on switch trials (PE switch costs: .027, $F(1, 62)=30.60$, $p<.001$) than younger adults (PE switch costs; .009, $F(1, 62)=3.645$, ns; older vs. younger: $t(62)=2.508$, $p<.05$), all other interactions were non-significant.

4. Discussion

Findings of the present study revealed that older adults show larger switch costs in same–different judgment task-switching paradigms. Such elevated switch costs for older adults cannot be attributed to general slowing (Cerella, 1990; Hartley, 2006; Salthouse, 1996), as log-transformed RTs showed the same patterns as raw RTs. This age-related increase in switch costs is critical because the literature has shown no consensus in age-related differences on *local* switch costs. Some researchers have suggested that age differences occur specifically under a more demanding task-switching setting (e.g., Lien et al., 2008), a conclusion that leaves the issue unresolved. The present study employed the same–different judgment task-switching paradigm to address this issue and found significant local switch costs for older adults.

Moreover, we manipulated both perceptual and conceptual dimensions for same–different judgments in the present study. The purpose was to examine whether there would be distinct age-related increases in switch costs for different types of judgment-dimension switches. The current results showed that although there was a significant main effect of judgment-dimension type, this effect did not interact with age and task transition. That is, regardless the judgment-dimension type required, there was a consistent and significant effect of age on switch costs. Equivalent age-related increases in switch costs for both judgment-dimension switches seems to conflict with existing literature showing age effects in processing speed for perceptual/non-lexical tasks, but not for verbal/lexical tasks (e.g., Hale, & Myerson, 1996; Jenkins, Myerson, Joerding, & Hale, 2000; Kliegl, Mayr, & Krampe, 1994; Myerson, & Hale, 1993; Verhaeghen, 2002; Verhaeghen et al., 2002). These discrepancies may be attributable to differences in task paradigms between the current study and previous investigations. In implicit memory research, equal age effects have also been observed in word stem completion priming effects for both perceptual and lexical components of repetition priming (Daselaar, Veltman, Rombouts, Raaijmakers, & Jonker, 2005). Therefore, future research is needed to elucidate the critical mechanism(s) responsible for task-specific, age-related changes. Nevertheless, in the more detailed analysis on RT distribution using the mixture model fitting approach, we observed differential mechanisms to account for an age-related increase in residual switch costs for different judgment-dimension switches (to be discussed later).

The second objective of the present study was to examine whether older adults maintained the ability to prepare themselves in advance for performing a task switch. We manipulated two different CSIs, 200 ms and 1000 ms, while keeping the influence of the passive decay process constant (RSI = 2200 ms). This manipulation is critical because if older adults can still benefit from longer preparatory intervals in a task-switching setting where advance preparation in selective attention is limited (see Lien et al., 2008; Meiran, & Marciano, 2002), the results would further strengthen previous reports of intact preparatory process for older adults. The present results indeed show that even with the current paradigms proving advanced preparation to be difficult, both younger and older adults benefited from a longer preparatory interval (i.e., switch costs were reduced with increasing CSI in both age groups). In addition, older adults showed an even larger reduction rate in switch costs than younger adults. The log-transformed RT analyses preserved the same results, suggesting that the larger performance benefit for older adults given a longer CSI could not be attributed to the general slowing effect. Such a result may eliminate the alternative hypothesis that older adults' intact preparatory component exists simply because such a preparatory process relies heavily on "bottom-up" processes rather than more demanding, "top-down" strategic processes (cf. Folk, & Lincourt, 1996). This is due to the fact that in the current same–different judgment paradigms, re-selective attention is more difficult to prepare (e.g., Santee, & Egeth, 1980).

Although both younger and older adults in the present study showed a significant reduction in switch costs with increasing CSIs, residual costs remained. Moreover, older adults were found to have larger residual switch costs. Thus, the third objective was to examine how manifested age effects on residual costs could be attributed to pure FTE, pure AP, or a combination of both accounts, by fitting the RT distribution to the generalized mixture model developed by de Jong (2000). The best fits of the mixture model showed that residual switch costs for younger adults in performing judgment switches could be fully explained by FTE theory, whereas for older adults performing conceptual-judgment switches, an AP account provided a better explanation of the results. The analyses also showed that older adults' elevated residual costs in performing perceptual-judgment switches might be attributable to an increased probabilistic failure to complete advance preparation, whereas their elevated residual costs in performing conceptual-judgment switches might be attributable to intrinsic limitations in their ability to attain a complete task-set reconfiguration during the preparatory interval. These findings suggest that older adults exhibited a specific rather than general deficit of attentional control (see also Lee, & Hsieh, 2009). Moreover, according to FTE theory, the observation of an increased probabilistic failure for older adults to complete advance preparation in perceptual dimension switch may suggest that older adults are more prone to goal neglect compared to younger adults. Why would the switch of same–different judgment based on perceptual dimensions invite more intermittent failures to complete advance preparation, but not the switch based on conceptual dimensions for older adults? We suspect that judgment switches based on color or shape may provide more opportunities for the strategic use of external aids for older adults, such as waiting until the arrival of the stimulus in which its physical dimension may serve as an external cue to reduce internal control effort; however, such a strategy may not be practical for switches based on conceptual dimensions.

Note that in the current scenario, we adopted de Jong's "failure-to-engage" model to evaluate the contribution of a probabilistic failure to complete advance preparation for task switching (a mixture model of the all-or-none preparation) and a fundamental limitation to complete advanced preparation (the "exogenous" component in Rogers, & Monsell, 1995, model). The model appeared to fit the current observed data well based on the evaluation of goodness of fit (see also Monsell, Sumner, & Waters, 2003; Nieuwenhuis, & Monsell, 2002). However, this does not mean that the binary-state (or discrete-state: "prepared" vs. "unprepared" trials) assumption in the FTE model is free of criticism. One major criticism lies in the strict assumption of a pure binary mixture of "prepared" and "unprepared" trials in the original FTE model. Brown, Lehmann, and Poboka (2006) provided a critical test of this strict binary assumption by examining whether the six RT distributions–collected from switch and repeat trials, each for three different RSIs–would share a common crossing point (Brown et al., 2006). Their rationale was derived from Falmagne (1968) proof that all binary mixture models should predict the same crossing point across all mixtures of the paired-distributions (i.e., changes in mixture probabilities). However, their RT distributions did not hold a fixed-point property. Nevertheless, instead of abandoning the FTE model, Brown et al. (2006) rescued it from a strict fixed-point prediction by relaxing the stringent assumption of binary all-or-none prepared states. For example, they amended the mixture model by allowing the prepared and unprepared mixing distributions to shift with RSI to fit the data.

Another criticism suggests that a partial-mapping preparation hypothesis could equally account for de Jong's (2000) findings (see Lien, Ruthruff, Remington, & Johnston, 2005). According to the partial-mapping preparation hypothesis, participants may always engage in preparation for a task switch if ample preparation time is given. However, this preparation is limited because participants can prepare for only a subset of S–R pairs in a trial; some S–R pairs may show little switch costs, while others show large switch costs. In other words, in contrast to de Jong's (2000) suggestion that people do not prepare for all of the tasks some of the time, the partial-mapping preparation hypothesis suggests that people prepare for some of the tasks (some S–R pairs) all of the time. The present study was not designed to clarify these alternative hypotheses. However, while we believe that these criticisms are plausible, they do not preclude the significant contribution of the current findings: there are dissociable aging effects on residual costs for different judgment switches.

Additionally, older adults showed higher error rates in some conditions–especially at 200 ms CSI and in switch conditions–than younger adults. Although we can exclude the possibility of speed-accuracy trade off to account for age-related increases in switch costs, it is important to demonstrate that age differences in switch costs could be unbiased by differences in accuracy. Thus, we selected a subgroup of young adults ($n=16$) and a subgroup of older adults ($n=16$) matched for numbers of errors, and re-analyzed the data. The patterns of the RT results for these subgroups remained the same, suggesting that age-related changes in RT switch costs and differential mechanisms to account for increased RT residual switch costs could not be attributed to differences in error rates.

Finally, the present results highlight the importance of incorporating the factor of task-specific effects for models of task switching. Although existing models tap various subcomponent processes, as of yet none has taken into account different processing characteristics, such as local switch costs, preparatory rate and residual switch costs for different types of switch tasks. In the present study, we consistently found elevated local switch costs for older adults with same–different judgment task-switching paradigms, whereas previous research using a different type of task-switching tasks (e.g., classification task) obtained equivocal results. In addition, to highlight this importance, the present study observed differential theoretical accounts (FTE vs. AP) for different types of switch tasks to account for an age-related increase in residual costs. Therefore, more research should be devoted to task-specific parameters and incorporating them into their models.

5. Conclusions

This study demonstrated that older adults exhibited a deficit in local switch costs on the same–different judgment task-switching paradigms, and such a deficit manifested itself on both perceptual and conceptual judgments. In contrast to these impairments, older adults maintained the ability to prepare in advance for a task switch even under a more difficult to prepare in advance same–different judgment task-switching paradigm. The reduction in switch cost was even larger for older adults. Nevertheless, older adults' ability to prepare in advance for a task switch could not prevent them from showing elevated residual switch costs compared to younger adults in the long preparatory interval. A detailed analysis using the mixture modeling technique suggests that older adults were more prone to exhibit failure to engage in advanced preparation in perceptual-judgment switches. Conversely, older adults' elevated switch costs in conceptual-judgment switches were not attributable to their increased intermittent failures to fully prepare in advance for a switch, but rather to their intrinsic limitation to attain a complete task-set reconfiguration during the preparatory interval. The findings obtained in the present study are thus consistent with the internal control deficit hypothesis set out by Lien et al. (2008). Additionally, these results imply that task-switching paradigms used in evaluating age-related differences in switch costs should be selected with caution to avoid underestimating age-related deficits.

Acknowledgments

This research was supported by a research grant from the National Science Council of the Republic of China, Taiwan given to Shulan Hsieh (contract no. NSC95-2413-H-006-020-MY3). We are indebted to Steven Yantis for generously providing us the fitting program generated from his laboratory using multinomial maximum likelihood method (MMLM; Yantis, Meyer, & Smith, 1991). Parts of these data were presented at the 50th Annual Meeting of the Psychonomic Society, November 2009 in Boston. We would like to thank the editor and the reviewers for their constructive comments for improving the manuscript.

Appendix

The present study followed de Jong's (2000) procedure for computing cumulative distribution functions (CDFs) by dividing the rank-ordered RTs for each participant and each condition into deciles and then computing the mean RT for each decile. De Jong used the following equations to formalize the FTE hypothesis: $F_{\text{switch, long PI}}(t)=\alpha F_{\text{prepared}}(t)+(1-\alpha)F_{\text{unprepared}}(t)$, where $_{\text{switch, long PI}}$ is the CDF for switch trials with a long preparation interval (PI). F_{prepared} (i.e., non-switch trials at long PI) and $F_{\text{unprepared}}$ (i.e., switch trials at short PI) are the theoretical CDFs for the prepared and unprepared state, and α is the mixing probability that preparation is carried out and completed during the long preparation interval, whereas $(1-\alpha)$ is the probability that preparation fails to be initiated even during the long preparation interval.

de Jong (2000) further suggested that the mixture model can be generalized to allow for the possible contribution of an additional exogenous component of task-set reconfiguration proposed by the AP hypothesis to residual switch costs. To estimate the contribution of this AP factor, de Jong (2000) added a parameter, δ, to represent the duration of this hypothetical exogenous component. The formula can be modified as: $F_{switch,\, long\, PI}(t) = \alpha F_{prepared}(t-\delta) + (1-\alpha)F_{unprepared}(t)$. According to de Jong (2000), with $\alpha = 1$, the generalized mixture model reduces to the pure AP hypothesis; with $\delta = 0$, the model reduces to the pure FTE hypothesis; and with intermediate cases, i.e., $0<\alpha<1$ and $\delta>0$, the model comprises a range of models in which various proportions of residual costs are attributed to failure to engage in advanced preparation (i.e., FTE) and to an additional exogenous component (i.e., AP). Thus, the distribution of RTs in switch trials with a long preparatory interval should be well fitted by a mixture of RTs from non-switch trials and switch trials with a short preparatory interval. The fitting technique yielded two free parameters in order to optimize the fit: the first parameter (α: a value between 0 and 1) representing the probability of FTE trials, and the second parameter representing the average duration (δ: in ms) of the exogenous component of the AP theory. Accordingly, fitting RTs to the generalized mixture model proposed by de Jong (2000) allows us to examine whether age differences in residual switch costs could be attributed solely to intermittent failures to take advantage of opportunities for advanced preparation, or whether they could be also attributed to the presence of fundamental preparatory limitations, as proposed by the AP hypothesis.

References

Allen, P. A., Ruthruff, E., & Lien, M. -C. (2007). Attention. In J. E. Birren (Ed.), *Encyclopedia of gerontology* (pp. 120—129)., 2nd ed. San Diego, CA: Academic Press.

Allport, D. A., Styles, E. A., & Hsieh, S. (1994). Shifting intentional set: Exploring the dynamic control of tasks. In C. Umilta, & M. Moscovitch (Eds.), *Attention and performance XV: Conscious and unconscious information processing* (pp. 421—452). Cambridge, MA: MIT Press.

Beck, A. T., Steer, R. A., & Brown, G. K. (1996). *Manual for the Beck Depression Inventory*, 2nd ed. San Antonio, TX: The Psychological Corporation.

Braver, T. S., Barch, D. M., Keys, B. A., Carter, C. S., Cohen, J. D., Kaye, J. A., et al. (2001). Context processing in older adults: Evidence for a theory relating cognitive control to neurobiology in healthy aging. *Journal of Experimental Psychology: General*, *130*, 746—763.

Brown, S., Lehmann, C., & Poboka, D. (2006). A critical test of the failure-to-engage theory of task switching. *Psychonomic Bulletin & Review*, *13*(1), 152—159.

Cerella, J. (1990). Aging and information-processing rates. In J. E. Birren, & K. W. Schaie (Eds.), *Handbook of the psychology of aging* (pp. 201—221)., 3rd ed. New York: Academic Press.

Daselaar, S. M., Veltman, D. J., Rombouts, S. A. R. B., Raaijmakers, J. G. W., & Jonker, C. (2005). Aging affects both perceptual and lexical/semantic components of word stem priming: An event-related fMRI study. *Neurobiology of Learning and Memory*, *83*(3), 251—262.

de Jong, R. (2000). An intention-activation account of residual switch costs. In S. Monsell, & J. Driver (Eds.), *Attention and performance XVIII: Control of cognitive processes* (pp. 357—376). Cambridge, MA: MIT Press.

de Jong, R. (2001). Adult age differences in goal activation and goal maintenance. *European Journal of Cognitive Psychology*, *13*, 71—89.

DiGirolamo, G. J., Kramer, A. F., Barad, V., Cepeda, N. J., Weissman, D. H., Milham, M. P., et al. (2001). General and task-specific frontal lobe recruitment in older adults during executive processes: A fMRI investigation of task-switching. *Neuroreport*, *12*(9), 2065—2071.

Falmagne, J. C. (1968). Note on a simple fixed-point property of binary mixtures. *British Journal of Mathematical & Statistical Psychology*, *21*, 131—132.

Folk, C. L., & Lincourt, A. E. (1996). The effects of age on guided conjunction search. *Experimental Aging Research*, *22*, 99—118.

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). Mini-mental state. A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research*, *12*, 189.

Grady, C. L., & Craik, F. I. M. (2000). Changes in memory processing with age. *Current Opinion in Neurobiology*, *10*(2), 224—231.

Hale, S., & Myerson, J. (1996). Experimental evidence for differential slowing in the lexical and nonlexical domains. *Aging, Neuropsychology, and Cognition*, *3*(2), 154—165.

Hartley, A. A. (1993). Evidence for the selective preservation of spatial selective attention in old age. *Psychology and Aging*, *8*, 371—379.

Hartley, A. A. (2006). The changing role of the speed of processing construct in the cognitive psychology of human aging. In J. E. Birren, & K. W. Schaie (Eds.), *Handbook of the psychology of aging* (pp. 183—208). Amsterdam: Elsevier.

Hartley, A. A., Kieley, J. M., & Slabach, E. H. (1990). Age differences and similarities in the effects of cues and prompts. *Journal of Experimental Psychology: Human Perception and Performance*, *16*(3), 523—537.

Hasher, L., & Zacks, R. T. (1988). Working memory, comprehension, and aging: A review and a new view. In G. Bower (Ed.), *The psychology of learning and motivation*, *Vol. 22*. (pp. 193—225)New York: Academic Press.

Jenkins, L., Myerson, J., Joerding, J. A., & Hale, S. (2000). Converging evidence that visuospatial cognition is more age-sensitive than verbal cognition. *Psychology and Aging*, *15*(1), 157—175.

Jersild, A. T. (1927). Mental set and shift.*Archives of Psychology* (Whole no. 89).

Jost, K., Mayr, U., & Rösler, F. (2008). Is task switching nothing but cue priming? Evidence from ERPs. *Cognitive, Affective, & Behavioral Neuroscience*, *8*(1), 74—84.

Kliegl, R., Mayr, U., & Krampe, R. T. (1994). Time-accuracy functions for determining process and person differences: An application to cognitive aging. *Cognitive Psychology*, *26*(2), 134—164.

Kramer, A. F., Hahn, S., & Gopher, D. (1999). Task coordination and aging: Exploration of executive control process in the task switching paradigm. *Acta Psychologica*, *101*, 339—378.

Kramer, A. F., Humphrey, D. G., Larish, J. F., & Logan, G. D. (1994). Aging and inhibition: Beyond a unitary view of inhibitory processing in attention. *Psychology and Aging*, *9*(4), 491—512.

Kray, J., Eber, J., & Lindenberger, U. (2004). Age differences in executive functioning across the lifespan: The role of verbalization in task preparation. *Acta Psychologica*, *115*, 143—165.

Kray, J., & Lindenberger, U. (2000). Adult age differences in task switching. *Psychology and Aging*, *15*, 126—147.

Lee, T. Y., & Hsieh, S. (2009). The limits of attention for visual perception and action in aging. *Aging, Neuropsychology, and Cognition*, *16*, 311—329.

Lien, M. C., Ruthruff, E., & Kuhns, D. (2008). Age-related differences in switching between cognitive tasks: Does internal control ability decline with age? *Psychology and Aging*, *23*(2), 330—341.

Lien, M. -C., Ruthruff, E., Remington, R. W., & Johnston, J. C. (2005). On the limits of advance preparation for a task switch: Do people prepare all the task some of the time or some of the task all the time? *Journal of Experimental Psychology: Human Perception and Performance*, *31*(2), 299—315.

Logan, G. D., & Bundesen, C. (2003). Clever homunculus: Is there an endogenous act of control in the explicit task-cuing procedure? *Journal of Experimental Psychology: Human Perception and Performance*, *29*, 575—599.

Madden, D. J. (2001). Speed and timing of behavioral processes. In J. Birren, & K. Schaie (Eds.), *Handbook of the psychology of aging* (pp. 288—312)., 5 ed. San Diego, CA: Academic Press.

Madden, D. J., Whiting, W. L., Spaniol, J., & Bucur, B. (2005). Adult age differences in the implicit and explicit components of top-down attentional guidance during visual search. *Psychology and Aging*, *20*(2), 317—329.

Mayr, U. (2001). Age differences in the selection of mental sets: The role of inhibition, stimulus ambiguity, and response-set overlap. *Psychology and Aging*, *16*, 96—109.

Mayr, U., & Kliegl, R. (2003). Differential effects of cue changes and task changes on task-set selection costs. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *29*(3), 362—372.

Mayr, U., & Liebscher, T. (2001). Is there an age deficit in the selection of mental sets? *European Journal of Cognitive Psychology*, *13*, 47—69.

Meiran, N. (1996). Reconfiguration of processing mode prior to task performance. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *22*, 1423—1442.

Meiran, N., Chorev, Z., & Sapir, A. (2000). Component processes in task switching. *Cognitive Psychology*, *41*, 211—253.

Meiran, N., Gotler, A., & Perlman, A. (2001). Old age is associated with a pattern of relatively intact and relatively impaired task-set switching abilities. *Journals of Gerontology: Psychological Sciences and Social Sciences*, *56*(2), P88—P102.

Meiran, N., & Marciano, H. (2002). Limitations in advance task preparation: Switching the relevant stimulus dimension in speeded same–different comparisons. *Memory & Cognition*, *30*, 540—550.

Monsell, S., & Mizon, G. A. (2006). Can the task-cuing paradigm measure an endogenous task-set reconfiguration process? *Journal of Experimental Psychology: Human Perception and Performance*, *32*(3), 493—516.

Monsell, S., Sumner, P., & Waters, H. (2003). Task-set reconfiguration with predictable and unpredictable task switches. *Memory & Cognition*, *31*(3), 327—342.

Moscovitch, M., & Winocur, G. (1992). The neuropsychology of memory and aging. In F. I. M. Craik, & T. A. Salthouse (Eds.), *The handbook of aging and cognition* (pp. 315—372). Hillsdale, NJ: Erlbaum.

Myerson, J., & Hale, S. (1993). General slowing and age invariance in cognitive processing: The other side of the coin. *Adult information processing: Limits on loss* (pp. 115—141). San Diego, CA, US: Academic Press.

Nicholson, R., Karayanidis, F., Bumak, E., Poboka, D., & Michie, P. T. (2006). ERPs dissociate the effects of switching task sets and task cues. *Brain Research*, *1095*(1), 107—123.

Nieuwenhuis, S., & Monsell, S. (2002). Residual costs in task switching: Testing the failure-to-engage hypothesis. *Psychonomic Bulletin & Review*, *9*(1), 86—92.

Phillips, L., & Henry, J. (2008). Adult aging and executive function. In V. Anderson, P. Anderson, & R. Jacobs (Eds.), *Executive function and the frontal lobes: A life span perspective* (pp. 57—80). Hove: Psychology Press.

Rogers, R. D., & Monsell, S. (1995). Costs of a predictable switch between simple cognitive tasks. *Journal of Experimental Psychology: General*, *124*, 207—231.

Ruge, H., Brass, M., Koch, I., Rubin, O., Meiran, N., & Cramon, D. Y. V. (2005). Advance preparation and stimulus-induced interference in cued task switching: Further insights from BOLD fMRI. *Neuropsychologia*, *43*(3), 340—355.

Salthouse, T. A. (1994). The aging of working memory. *Neuropsychology*, *8*(4), 535—543.

Salthouse, T. A. (1996). The processing-speed theory of adult age differences in cognition. *Psychological Review*, *103*, 403—428.

Salthouse, T. A., Fristoe, N., McGuthry, K. E., & Hambrick, D. Z. (1998). Relation of task switching to speed, age, and fluid intelligence. *Psychology and Aging*, *13*, 445—461.

Santee, J. L., & Egeth, H. E. (1980). Selective attention in the speeded classification and comparison of multidimensional stimuli. *Perception & Psychophysics*, *28*, 191—204.

Schneider, D. W., & Logan, G. D. (2005). Modeling task switching without switching tasks: A short-term priming account of explicitly cued performance. *Journal of Experimental Psychology: General*, *134*(3), 343—367.

Spector, A., & Biederman, I. (1976). Mental set and mental shift revisited. *American Journal of Psychology*, *89*, 669—679.
Verhaeghen, P. (2002). Age differences in efficiency and effectiveness of encoding for visual search and memory search: A time-accuracy study. *Aging, Neuropsychology, and Cognition*, *9*(2), 114—126.
Verhaeghen, P., Cerella, J., Bopp, K. L., & Basak, C. (2005). Aging and varieties of cognitive control: A review of meta-analyses on resistance to interference, coordination, and task switching, and an experimental exploration of age sensitivity in the newly identified process of focus switching. In R. W. Engle, G. Sedek, U. von Hecker, & D. N. McIntosh (Eds.), *Cognitive limitations in aging and psychopathology* (pp. 160—189). Cambridge, UK: Cambridge University Press.
Verhaeghen, P., Cerella, J., Semenec, S. C., Leo, M. A., Bopp, K. L., & Steitz, D. W. (2002). Cognitive efficiency modes in old age: Performance on sequential and coordinative verbal and visuospatial tasks. *Psychology and Aging*, *17*(4), 558—570.
West, R. J. (1996). An application of prefrontal cortex function theory to cognitive aging. *Psychological Bulletin*, *120*, 272—292.
Yantis, S., Meyer, D. E., & Smith, J. E. K. (1991). Analyses of multinomial mixture distributions: New tests for stochastic models of cognition and action. *Psychological Bulletin*, *110*, 350—374.