Available online at www.sciencedirect.com
SCIENCE DIRECT®

International Journal of Psychophysiology 59 (2006) 30 – 39

INTERNATIONAL JOURNAL OF PSYCHOPHYSIOLOGY

www.elsevier.com/locate/ijpsycho

A cross-sectional examination of age and physical activity on performance and event-related brain potentials in a task switching paradigm

Charles H. Hillman, Arthur F. Kramer*, Artem V. Belopolsky, Darin P. Smith

Beckman Institute, University of Illinois, 405 North Mathews Avenue, Urbana, Illinois 61801, USA

Received 11 January 2005; accepted 8 April 2005

Abstract

Younger and older physically active and sedentary adults participated in a task switching paradigm in which they performed a task repeatedly or switched between two different tasks, while measures of response speed, response accuracy, P3 amplitude, and P3 latency were recorded. Overall, response times were faster and midline P3 amplitudes were larger for the active than for the sedentary participants. P3 latencies discriminated between active and sedentary individuals on trials in which multiple task sets were maintained in memory and task switches occurred unpredictably but not in blocks of trials in which a single task was repeatedly performed. Results are discussed in terms of the specificity and generality of physical activity effects on cognition.

Keywords: Exercise; Executive control; P3; ERP; Aging; Fitness

Over the past several decades there has been an increasing interest in the influence of physical activity and in particular aerobic exercise, on human cognition. Early studies of this relationship often examined the influence of physical activity differences, for both younger and older adults, on the performance of simple and choice reaction time (RT) tasks. For example, Spirduso and Clifford (1978) found that older physically active adults were significantly faster on a variety of different RT and movement time tasks than older sedentary adults. These initial observations were confirmed in numerous subsequent studies of cross-sectional physical activity differences on the performance and cognition of older adults (see Etnier et al., 1997 for a review). The literature that has examined whether younger adults show similar physical activity benefits on the performance of cognitive tasks has been more equivocal (Lupinacci et al., 1993; Rikli and Busch, 1986), perhaps as a result of the generally moderate to high activity levels of younger adults in the cohorts that have been studied.

The relatively strong relationship between physical activity and cognition, particularly with older adults, has not always been observed with randomized clinical trials in which an aerobic training group is compared to a non-aerobic control group. However, a number of intervention studies have reported improvements in particular aspects of cognition with physical activity training (see Colcombe and Kramer, 2003 for a review of this literature). Interpretation of the results from these studies is complicated by differences in the length, intensity, and type of training regimens, the age, health, and beginning and ending cardiovascular fitness levels of the study participants, the methods used for the assessment of cardiorespiratory fitness, and the tasks used to index perceptual, cognitive, and motor function improvements.

Given the relatively small sample of individuals who have participated in each of these studies, Colcombe and Kramer (2003) performed a meta-analysis on the randomized clinical studies of physical activity effects on cognition in an effort to determine whether (a) a reliable physical activity effect could be discerned with the additional power that is gained when aggregating data across studies and (b) if so, which factors moderate the effects of physical activity on cognition. Several interesting and potentially important results were obtained. First, a clear and significant effect of aerobic exercise training was found. Second, aerobic exercise training had both general and selective effects on cognitive function. Although physical activity effects were observed across a wide variety of tasks and cognitive processes, the effects were largest for those tasks

* Corresponding author.
E-mail address: akramer@cyrus.psych.uluc.ac (A.F. Kramer).

0167-8760/$ - see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.ijpsycho.2005.04.009

that involved executive control processes (i.e., planning, scheduling, working memory, interference control, task coordination). Executive control processes have been found to decline substantially as a function of aging (West, 1996) as have the brain regions that support them (Raz, 2000). Therefore, the results of the meta-analysis suggest that even processes that are quite susceptible to age-related changes appear to be amenable to intervention.

Research employing event-related brain potentials (ERPs) has further established that physical activity may be beneficial to cognitive function in older adults (Dustman et al., 1990; Hillman et al., 2004, 2002). Habitual participation in aerobic forms of exercise has been associated with decreased differences in the neuroelectric profile between older and younger individuals, indicating that it may protect against cognitive aging. In particular, the P3 component of the ERP has been especially useful in understanding the relationship between physical activity and aging, since differences in the amplitude and latency have been observed that are indicative of the attentional resources allocated in the updating of working memory, and the speed of cognitive processing, respectively. Findings suggest that exercise participation may play a role in maintaining efficiency of cognitive performance with advanced age by increasing P3 amplitude and decreasing P3 latency (Hillman et al., 2002, 2004).

In the present study, we further examined the relationship between physical activity and cognition by asking physically active and sedentary younger and older adults to perform a task switching paradigm. This paradigm has been used to study selective aspects of executive control (e.g., Rogers and Monsell, 1995) and entails comparisons between three different conditions (repeated task trials in task-homogenous blocks, switch trials in task-heterogeneous blocks, and non-switch or repeated task trials in task-heterogeneous blocks). Comparisons among these conditions enable us to distinguish separate executive control components and to determine interactions among them. In task-homogenous blocks, participants perform the same task on every trial, while in task-heterogeneous blocks two (or more) tasks are intermixed. Task-heterogeneous blocks consist of two types of trials: switch trials, in which the task is different than the one in the preceding trial, and non-switch trials, in which the task is the same as the task in the preceding trial.

The difference between performance on switch trials and non-switch trials within task-heterogeneous blocks has been termed *local switch costs* (Meiran, 1996). Local switch costs reflect the effectiveness of executive control processes responsible for the activation of the currently relevant task set and the deactivation of the task set that was relevant on the previous trial. Another aspect of task switching is *global switch costs*, and is defined as the difference in performance between task-heterogeneous blocks and task-homogenous blocks. Global switch costs reflect the efficiency of maintaining multiple task sets in working memory as well as the selection of the task to be performed next (Kray and Lindenberger, 2000).

Many studies have shown age effects in local switch costs to be rather small or absent when age effects in general slowing are taken into account (e.g., Kray and Lindenberger, 2000; Mayr, 2001; but see De Jong, 2001; Kray et al., 2002). However, studies of task switching have often found age effects to be much more robust and pronounced in global switch costs (Kray and Lindenberger, 2000; Mayr, 2001). Importantly, older adults' performance deficits in global switch costs remain reliable after controlling for age effects in general slowing.

In the present study we tested several hypotheses within the context of a task switching paradigm in which the task to be performed next was cued upon the presentation of the stimulus and the order of tasks (in the heterogeneous trial blocks) was random and unpredictable. First, we examined the hypothesis that physical activity would positively influence task switching performance for both younger and older adults. As discussed above, previous research has been equivocal with respect to whether physical activity effects are equivalent for younger and older adults or larger for older adults—although a recent meta-analysis (Etnier et al., 1997) suggests age-equivalence. Given that the task we employed has shown strong aerobic fitness effects for older adults in a previous study (Kramer et al., 1999), we hypothesize that it will be sufficiently sensitive to detect physical activity effects for both younger and older adults in the present study. Second, we hypothesize that physical activity will have a larger effect on trials in the task-heterogeneous or switching blocks than in the task-homogenous (repeated task) blocks. We suggest that this will be the case because performance in the task-heterogeneous blocks requires more extensive executive control processes, the very processes that appear to be most sensitive to physical activity effects (Colcombe and Kramer, 2003; Kramer et al., 1999).

Third, we hypothesize that the event-related brain potential (ERP) measures, and specifically the amplitude and latency of the P3 component, will be more sensitive to physical activity effects than measures of performance (see Hillman et al., 2004). We believe that this will be the case because components of the ERP are selectively sensitive to processes that intervene between the encoding of the task-relevant stimuli and the production of a response. As a result of this characteristic we expect that the P3 measures will enable us to more precisely gauge the effects of physical activity than the performance measures. In the present study we utilize measures of P3 amplitude and latency to examine the nature and specificity of physical activity effects on important components of processing—that is, the speed of processing and the updating of memory representations during the performance of switch and non-switch trials.

1. Method

1.1. Participants

Sixty-six participants (34 male) were recruited based on age and physical activity history and placed into one of four gender-balanced groups: older physically active, older sedentary, younger physically active, and younger sedentary. Table 1 lists participants' demographic information and physical

Table 1
Group means (SEM) for participant characteristics

Measure	Group			
	Older active	Older sedentary	Younger active	Younger sedentary
n	17	15	18	16
Age	63.7 (.9)[a]	65.9 (.8)[a]	19.4 (.3)[b]	19.4 (.2)[b]
Years of education	17.7 (.7)[a]	16.7 (.8)[a]	13.7 (.3)[b]	13.8 (.3)[b]
Mini Mental State Exam	27.8 (.4)[a]	29.1 (.3)[b]	28.9 (.3)[a]	29.2 (.3)[a,b]
Beck Depression Inventory	4.7 (.8)[a]	4.8 (1.0)[a]	2.4 (.3)[b]	3.3 (.9)[a,b]
Yale: total hours of activity	33.4 (3.4)[a]	16.9 (2.8)[b]	23.9 (2.5)[a,b]	10.0 (1.7)[b]
Yale: kilocalorie expenditure	8697.5 (755.6)[a]	3452.5 (563.5)[b]	7508.8 (768.8)[a]	2408.8 (363.8)[b]
Yale: activity index	57.1 (3.6)[a]	27.1 (2.3)[b]	69.7 (4.0)[a]	48.8 (2.7)[b]

Values that share a common superscript are not significantly different at the $p \leq .05$. Thirty is the maximum obtainable score on the Mini Mental State Exam, and 63 is the maximum obtainable score on the Beck Depression Inventory.

activity characteristics. All individuals reported being free of neurological disorders, cardiovascular disease, any medications that influence central nervous system function, and had corrected to normal vision.

1.2. Procedure

Participants were initially screened via telephone regarding physical activity habits and general health status, and those that participated in aerobic exercise (e.g., walking, running, cycling, swimming, etc.) less than 1 h per week or more than 5 h per week were invited to the laboratory. Upon arrival to the laboratory, participants' provided informed consent and completed the Beck Depression Inventory, a general health history questionnaire, the Mini Mental State Exam and the Yale Physical Activity Survey for Older Adults (YPAS). The YPAS measures activities of daily living and is comprised of three subscales: total hours of activity, kilocalorie expenditure, and the Yale Summary Index, which estimates the average amount of physical activity during the previous month and is highly correlated with VO_2 peak in 60–80 year old adults.

Participants were then seated in a comfortable chair and prepared for neuroelectric measurement in accordance with the Society for Psychophysiological Research guidelines. Electroencephalograms (EEG) were measured from the following midline and lateral sites: F3, Fz, F4, C3, Cz, C4, P3, Pz, P4, and A2 (i.e., right mastoid) and referenced to the left mastoid (A1). AFz served as the ground and electo-oculographic activity was collected from electrodes placed above and below the right orbit and on the outer canthus of each eye to record bipolar eye movements. Impedance values for all electrodes were ≤ 5 kΩ. Participants were then given task instructions and allowed 10 practice trials prior to each of the three blocks.

1.3. Task

Participants were asked to switch back and forth between two different tasks that used the same numeric stimuli, which appeared in the center of the computer screen. In one condition, participants determined whether the digit presented was greater or less than 5; and in the other condition, participants determined whether the digit presented was odd or even. During each trial a solid or dashed outline cue appeared simultaneously with the numeric stimuli instructing participants as to which decision to make (i.e., greater or less than 5, odd/even). Participants received three blocks of stimuli. The first two blocks were the homogenous conditions, in which only one task was performed, and were counterbalanced across participants. The third block consisted of the task-heterogeneous condition in which participants were required to switch between equiprobable task sets on some trials and repeatedly perform the same task over trials in other cases. That is, in the heterogeneous block the two tasks alternated randomly, with seven consecutive trials as the maximum number that were performed repeatedly for each task. Thus, all trials in the heterogeneous block were categorized into either switch or non-switch conditions. White numeric stimuli were presented on a black background for 200 ms, with a 2000 ms interstimulus interval from stimulus offset to onset. Participants completed 50 trials in each of the homogenous conditions and 256 trials in the heterogeneous condition.

1.4. Apparatus and measures

A 64-Channel Neuroscan Synamps system was used to digitally amplify the EEG signal 500 times with a DC to 70 Hz-filter and a 60-Hz notch filter. Continuous data were recorded on-line using Scan 4.2 software installed on an 850-MHz microcomputer.

1.5. Data reduction

Continuous data were re-referenced off-line to averaged ears, merged with behavioral data, and the Semlitsch et al. (1986) algorithm was applied to correct for eye movement artifacts. One-second epochs (beginning-100 ms pre-stimulus) were created from continuous data and baseline corrected. Data were filtered using a 30-Hz low pass cutoff and artifact detection excluded trials containing amplitude excursions of ±100 μV. The P3 component was identified in artifact-free trials accompanied by correct responses. P3 was defined as the largest positive-going peak within a 275–750 ms latency window. Amplitude was measured as a change score from the pre-stimulus baseline and peak latency was defined as the time point of the maximum amplitude. Amplitude analyses for group comparisons involving the region or site factors included the McCarthy and Wood (1985) normalization procedure (i.e., root-mean-square), which standardizes differences in the topographic distribution of the scalp activity across groups. The N1, P2, and N2 components were reduced in a similar manner as the P3. However, analyses indicated that there was no relationship between physical activity and these ERP components. Accordingly, they will not be discussed further.

1.6. Statistical analysis

Separate analyses were conducted to examine global and local switch costs. Global switch cost analyses examined differences between homogenous and heterogeneous conditions, local switch cost analyses examined differences between switch and non-switch trials during the heterogeneous block condition. The between-groups factors were Age (younger, older) and Physical Activity (physically active, sedentary). The within-groups factors were Condition, Region, and Site. Condition referred to the global or local costs (global switch cost analyses: homogenous vs. heterogeneous trials; local switch cost analyses: switch vs. non-switch trials). Region referred to frontal, central, and parietal scalp locations. Site referred to electrodes overlying the left, midline, and right scalp locations.

In all instances, the Wilks' Lambda statistic was used for analyses with three or more within-subject levels, and post hoc comparisons were conducted using univariate ANOVAs and Bonferroni-corrected paired samples *t* tests. The alpha level was $p = .05$ for all analyses prior to Bonferroni adjustments.

2. Results

Given the number of variables included in the study design, not all significant findings are discussed in the Results section. Only those findings that involve age, physical activity, and condition are presented.

2.1. Participant characteristics

Confirming our initial screening, a main effect was found for Physical Activity participation, F's $(1,62) > 32.2$, $p < .001$, $\eta^2 = .34$, with the physically active groups reporting more activity than the sedentary groups across all three subscales of the YPAS (i.e., total hours of activity, kilocalorie expenditure, Yale Summary Index). In addition, significant Age effects were observed for the YPAS total hours of activity and Yale Summary Index subscales, F's $(1,62) = 9.3$, $p < .003$, $\eta^2 = .13$, with older adults reporting increased hours of activity, but a lower Summary Index, suggesting fewer of their total hours of activity were spent engaging in physical activity compared to younger adults. That is, older adults reported increased hours of participation across various activities of daily living, but fewer overall hours were spent engaged in aerobic activities, relative to younger adults. Age effects were also observed for the number of years of education, F $(1,62) = 36.5$, $p < .001$, $\eta^2 = .37$, the BDI, F $(1,62) = 6.2$, $p < .02$, $\eta^2 = .09$, and the MMSE, F $(1,62) = 4.2$, $p < .05$, $\eta^2 = .06$, with older adults reporting more years of education, higher scores on the BDI, and lower scores on the MMSE. However, it should be noted that the mean age differences reported herein were small and all participants' scores were below the cutoff indicative of depression or dementia (see Table 1).

2.2. Behavioral measures

2.2.1. Global switch

The omnibus analysis for RT exhibited main effects of Age, F $(1,62) = 54.3$, $p < .001$, $\eta^2 = .47$, Physical Activity, F $(1,62) = 4.0$, $p = .05$, $\eta^2 = .06$, and Condition, F $(1,62) = 1023.0$, $p < .001$, $\eta^2 = .94$, with results indicating that younger adults responded faster than older adults, physically active adults responded faster than sedentary adults, and all participants responded faster during the homogenous condition, compared to the heterogeneous condition (see Table 2). An Age × Condi-Condition interaction was also observed, F $(1,62) = 53.8$, $p = .001$, $\eta^2 = .47$, with follow up Bonferroni-corrected *t* tests indicating that younger adults were faster than older adults during both conditions, t's $(1,64) \geq 3.8$, $p < .001$; however, the group differences were increased during the heterogeneous condition. A Condition main effect was observed for response accuracy, F $(1,62) = 68.4$, $p = .001$, $\eta^2 = .52$, indicating greater

Table 2
Means (SEM) for RT and response accuracy during global and local switch comparisons for each of the four groups

Group	Global switch			Local switch		
	Heterogeneous	Homogenous	Global switch cost	Switch	Non-switch	Local switch cost
RT						
Older phys. active	1165.5 (36.4)	605.7 (19.9)	559.8 (16.5)	1274.8 (42.9)	1068.0 (33.6)	206.8 (9.3)
Older sedentary	1210.0 (38.7)	578.7 (21.1)	631.3 (17.6)	1337.8 (45.7)	1097.4 (35.8)	240.4 (9.9)
Younger phys. active	835.7 (35.4)	471.9 (19.3)	363.8 (16.1)	881.5 (41.7)	792.6 (32.7)	88.9 (9.0)
Younger sedentary	938.9 (37.5)	556.0 (20.5)	382.9 (17.0)	980.0 (44.2)	901.2 (34.6)	78.8 (9.6)
Accuracy						
Older phys. active	85.1 (2.8)	97.2 (.7)	−12.1 (2.1)	82.6 (3.3)	87.5 (2.5)	−4.9 (0.8)
Older sedentary	80.5 (3.0)	96.2 (.8)	−15.7 (2.2)	76.0 (3.5)	85.0 (2.7)	−9.0 (0.8)
Younger phys. active	88.4 (2.7)	95.5 (.7)	−7.1 (2.0)	86.6 (3.2)	90.3 (2.4)	−3.7 (0.8)
Younger sedentary	86.9 (2.9)	97.0 (.7)	−10.1 (2.2)	84.6 (3.4)	89.1 (2.6)	−4.5 (0.8)

accuracy during the homogenous, compared to heterogeneous, conditions.

2.2.2. Local switch

For RT, the same three main effects of Age, F (1,62)=65.9, p<.001, η^2=.52, Physical Activity, F (1,62)=4.0, p=.05, η^2=.06, and Condition, F (1,62)=197.6, p<.001, η^2=.76, and the Age × Condition interaction, F (1,62)=40.8, p<.001, η^2=.40, observed for the global switch condition were also found for the local switch condition. For response accuracy, the same Condition main effect, F (1,62)=48.5, p<.001, η^2=.44, found for the global switch condition was observed for the local switch condition (see Table 2).

2.3. P3 amplitude

Fig. 1 presents the ERP waveforms for all subject groups and experimental conditions.

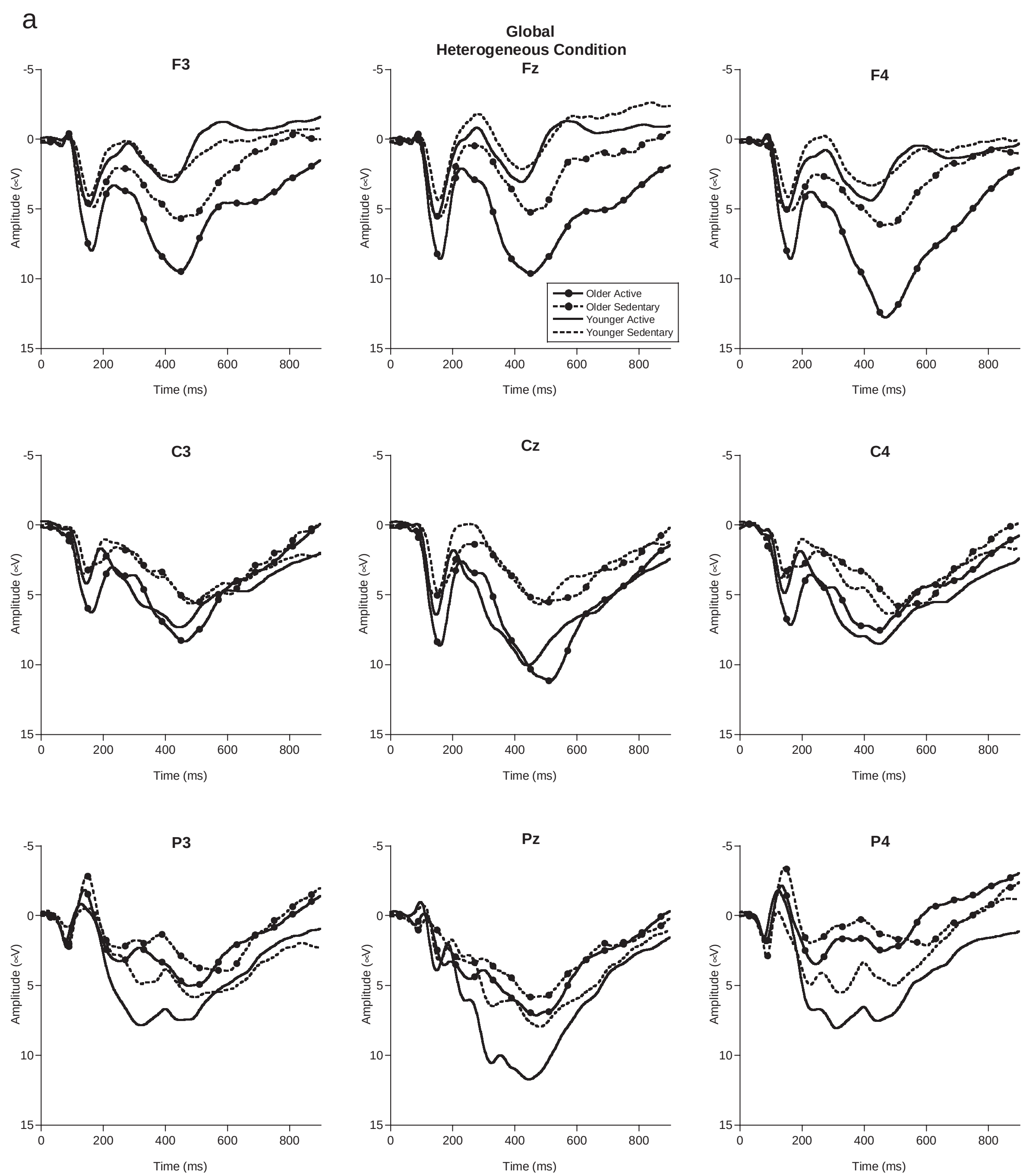

Fig. 1. Grand averaged ERP waveforms for the four groups (older physically active, older sedentary, younger physically active, younger sedentary) at each electrode site during the global heterogeneous (1a), global homogenous (1b), local heterogeneous switch (1c), and local heterogeneous non-switch (1d) trials. Note that physically active participants exhibited increased P3 amplitude at central and parietal midline, relative to lateral, sites, and faster P3 latency for the heterogeneous condition in the global comparison and for both the switch and non-switch conditions in the local comparison.

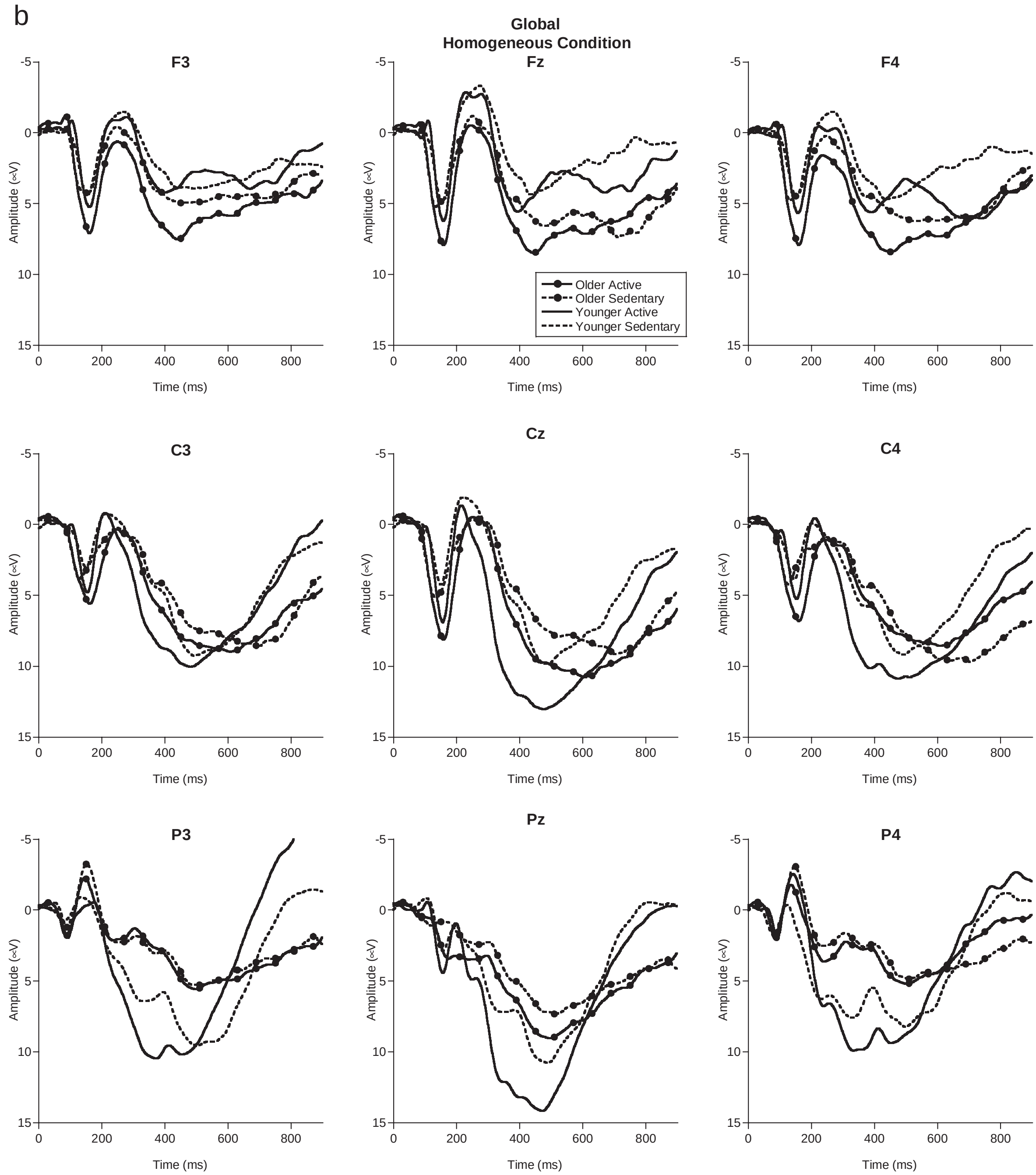

Fig. 1 (*continued*).

2.3.1. Global switch

A Physical Activity × Site interaction was observed, F $(2,61) = 5.9$, $p = .005$, $\eta^2 = .16$, indicating that physically active, compared to sedentary, participants had larger P3 amplitude along midline sites, $t\ (1,64) = 2.5$, $p = .017$, and no group differences at lateral sites. This 2-way interaction was superseded by a Physical Activity × Region × Site interaction, $F\ (4,59) = 4.0$, $p = .006$, $\eta^2 = .21$. Breaking down the 3-way interaction by examining Region × Site for both groups (i.e., physically active and sedentary) revealed a significant Region × Site interaction for the physically active group, F $(4,31) = 12.1$, $p < .001$, $\eta^2 = .61$. Follow up univariate ANOVAs indicated Site effects at all three regions (frontal, central, parietal), F's $(2,33) \geq 5.8$, $p \leq .007$, $\eta^2 \geq .26$. Post hoc Bonferroni corrected t tests indicated that physically active participants had increased P3 amplitude frontally at F3 compared to F4, centrally at Cz compared to C3 and C4, and parietally at Pz compared to P3 and P4, t's $(1,34) \geq 2.6$, $p \leq .01$ (see Fig. 1a and b). No such interaction was observed for the sedentary group. However, main effects of Region, $F(2,29) = 9.8$, $p = .001$, $\eta^2 = .40$, and Site, $F(2,29) = 4.7$, $p < .02$, $\eta^2 = .25$, were observed, indicating that sedentary participants had increased amplitude at parietal compared to frontal and central regions, t's $(1,30) \geq 3.1$, $p \leq .005$, and at the midline compared to the right lateral sites, $t\ (1,30) \geq 3.1$, $p < .005$.

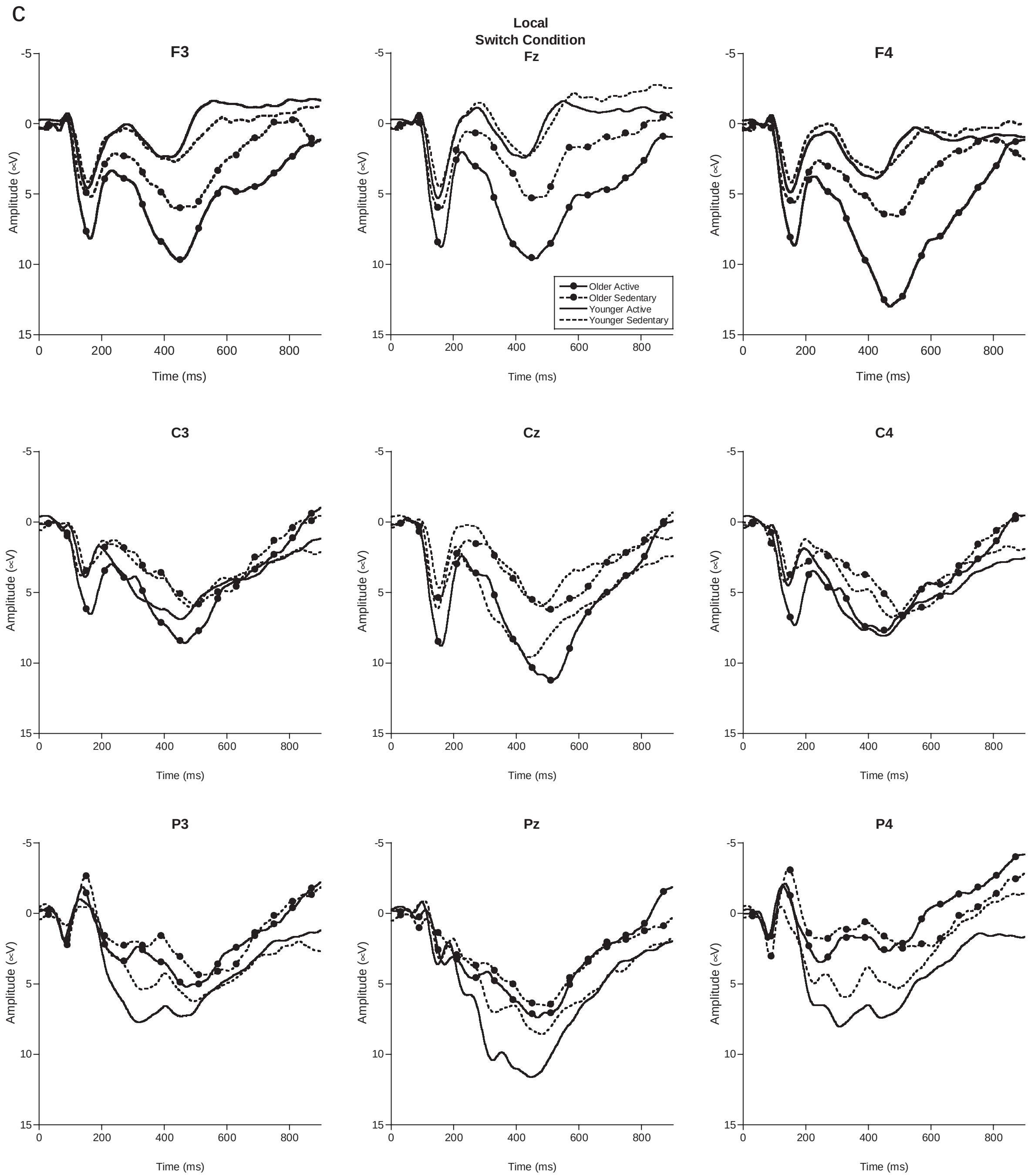

Fig. 1 (*continued*).

In addition, a Condition main effect was observed, F $(1,62)=5.3$, $p=.02$, $\eta^2=.08$, which indicated increased amplitude for the homogeneous ($M=21.6$, SE=.67) compared to the heterogeneous ($M=20.3$, SE=.64) condition. Further, an Age × Condition effect, F $(1,62)=12.5$, $p=.001$, $\eta^2=.17$, indicated that younger adults exhibited increased amplitude compared to older adults for the homogeneous condition, t $(1,64)=2.3$, $p=.025$; an effect that was not observed for the heterogeneous condition. Lastly, an Age × Region interaction, F $(2,61)=8.1$, $p=.001$, $\eta^2=.21$, was observed that indicated increased amplitude frontally and decreased amplitude parietally for older compared to younger adults, t $(1,64)\geq 3.3$, $p\leq .001$, with no groups differences observed at the central region.

2.3.2. Local switch

A Physical Activity × Site interaction was observed, F $(2,61)=3.6$, $p=.03$, $\eta^2=.12$, similar to that found for the global switch comparison (see Fig. 1c and d). Post hoc Bonferroni-corrected t tests indicated increased amplitude at the midline, relative to the lateral, sites for physically activity participants, t's$(1,34)=2.7$, $p\leq .01$. No such effect was observed for the sedentary participants ($p\geq .24$). In addition, a similar Age × Region interaction, F $(2,61)=8.7$, $p<.001$,

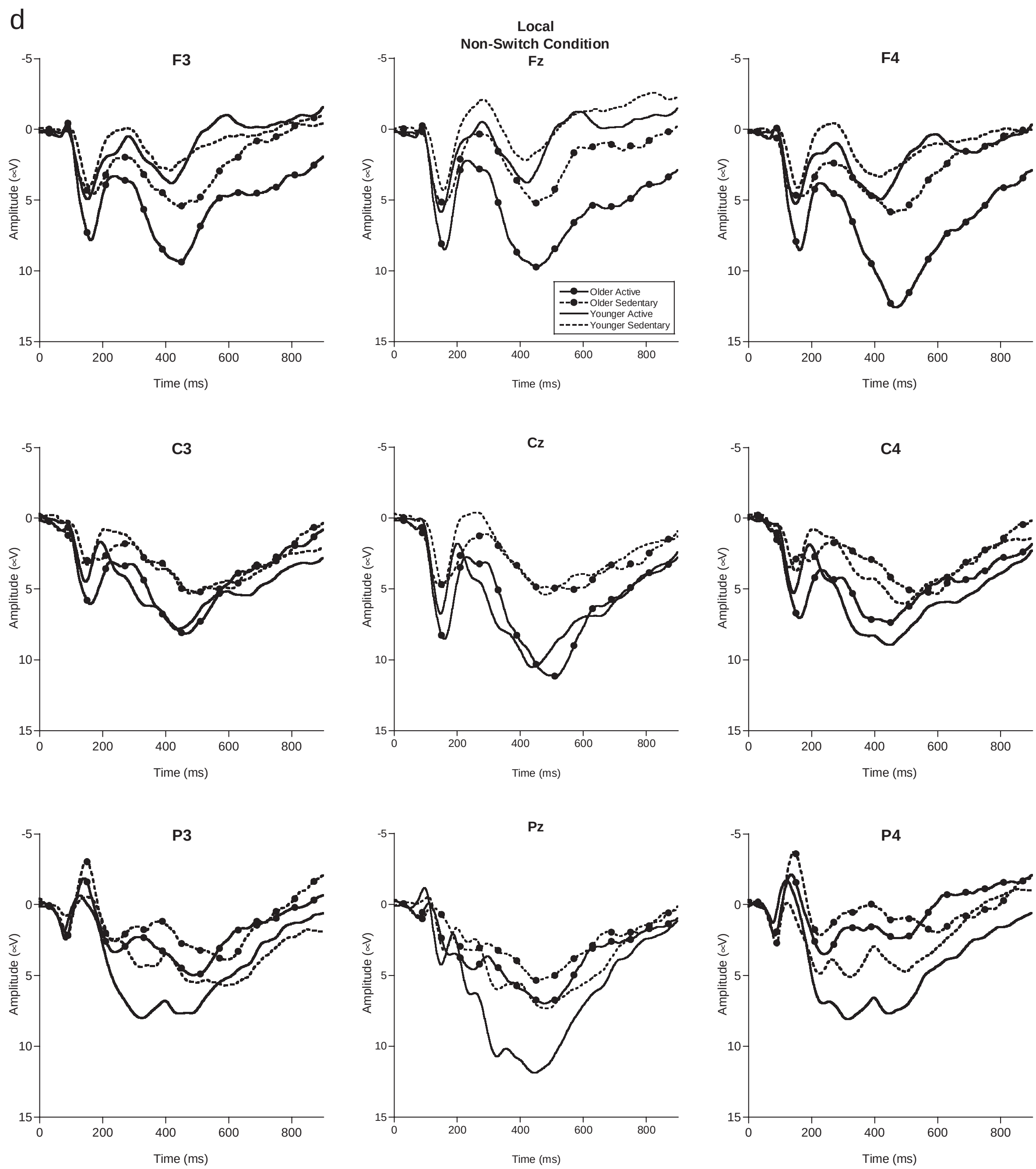

Fig. 1 (*continued*).

$\eta^2=.22$, was found for the local switch cost compared to the global switch cost. However, a Condition main effect was not observed, rather a significant Condition × Region interaction, F (2,61)=4.6, $p=.01$, $\eta^2=.13$, revealed decreased amplitude frontally and increased amplitude parietally for the switch compared to the non-switch trials, t's(1,65)=2.7, $p\leq.01$, with no differences in condition observed over the central region.

2.4. P3 latency

2.4.1. Global switch

Main effects of Age, F (1,62)=4.7, $p=.03$, $\eta^2=.07$, and Condition, F (1,62)=289.5, $p<.001$, $\eta^2=.82$, were observed with faster P3 latency for younger ($M=426.2$, SE=3.3) compared to older ($M=436.5$, SE=3.4) adults, and for homogeneous ($M=403.1$, SE=1.8) compared to the heterogeneous ($M=459.6$, SE=3.7) condition. A marginal physical activity main effect was observed, F (1,62)=3.4, $p=.07$, $\eta^2=.05$, with faster P3 latency for physically active, than for sedentary, participants. In addition, a Physical Activity × Condition interaction was observed, F (1,62)=3.9, $p=.05$, $\eta^2=.06$, that was superceded by a Physical Activity × Condition × Region interaction, F (2,61)=3.9, $p=.025$, $\eta^2=.11$. Breaking down the 3-way interaction, significant Physical Activity × Condition interactions were observed at central and parietal regions, F's (1,64)$\geq$4.0, $p\leq.05$, $\eta^2\geq.06$.

Follow up Bonferroni-corrected t tests indicated a marginal effect at the central region, t (1,64)=2.0, $p<.05$, and a significant effect at the parietal region, t (1,64)=2.5, $p=.01$, with faster P3 latencies for physically active, relative to sedentary, participants only for the heterogeneous condition.

2.4.2. Local switch

A physical activity main effect was observed, F (1,62)=4.1, $p<.05$, $\eta^2=.06$, with faster P3 latency for physically active (M=457.5, SE=5.0), relative to sedentary (M=472.2, SE=5.3), participants. In addition, a marginally significant Physical Activity × Region interaction was found, F (2,61)=3.0, $p=.056$, $\eta^2=.09$, with post hoc tests indicating that physically active, compared to sedentary, participants had faster P3 latency at the central region, $t(1,64)=2.0$, $p<.05$, and at the parietal region, $t(1,64)=2.5$, $p=.015$.

3. Discussion

The present study was conducted to extend the body of research that has examined the relationship between physical activity and human cognition. Three specific hypotheses were tested in our study. First, we tested the hypothesis that physical activity would positively influence task switching performance for both younger and older adults. Indeed, we found this to be the case. Physically active individuals responded more quickly as indexed by both the global and local switch analyses, and also demonstrated faster P3 latencies and greater amplitude P3′s at central and parietal scalp sites than sedentary participants. Given the sensitivity of P3 measures (i.e., P3 latency being sensitive to perceptual/central processing and P3 amplitude reflecting attentional allocation to the stimuli in the service of memory updating—see Polich, 1997) to a subset of processes reflected by RT, these data suggest that physical activity influences both perceptual/central as well as response-related processing for both younger and older adults, and indeed does so in a reasonably challenging task known to reflect multiple components of executive control.

Second, we tested the hypothesis that physical activity would have a larger effect on trials in the heterogeneous blocks than in the homogenous (repeated task) blocks. We suggested that this would be the case because performance in the heterogeneous blocks reflects greater demands on executive control processes, the very processes that appear to be most sensitive to physical activity effects (Kramer et al., 1999; Colcombe and Kramer, 2003). This effect was not significant for the response performance measures (i.e., speed and accuracy), although the trend was in the predicted direction for reaction time. However, there was a significant interaction between activity level and condition for the P3 latency measure such that P3 latency discriminated between physically active and sedentary individuals for the trials in the heterogeneous blocks (451 vs. 467 ms) but not in the homogenous blocks (400 vs. 401 ms). These data are consistent with the speculation that executive control processes, and in the present case processes that reflect the efficiency of maintaining multiple task sets in working memory as well as the selection of the task to be performed next, are particularly sensitive to physical activity (Colcombe and Kramer, 2003).

Third, we tested the hypothesis that P3 amplitude and latency would be sensitive measures of physical activity effects. Indeed, this was clearly the case given the finding of differences in P3 amplitude and P3 latency between active and sedentary groups. Such results suggest, based upon our knowledge of the functional significance of P3, that more physically active individuals are both able to more effectively deploy attentional resources and more quickly process task-relevant events in tasks requiring frequent updating and switching of task sets. In fact, the P3 latency measure indicated that this processing speed benefit was specific to the more challenging task conditions; that is the conditions under which older adults have been shown to suffer the greatest disadvantage (Raz, 2000). The fact that these effects were statistically equivalent for younger and older adults suggests considerable cognitive and neural plasticity for older adults and the possibility of effective interventions for age-related cognitive decline. Of course, these results also suggest that exercise training interventions may also be quite effective during young adulthood.

It is important to note that although our analyses of RT and P3 amplitude and latency suggest differential processing in the task switching paradigm as a function of the amount of physical activity, the analyses do, for the most part, suggest general rather than process specific effects. That is, the great majority of the behavioral and ERP physical activity effects were obtained independently of the task conditions. For example, main effects of physical activity were obtained across both comparisons for RT (i.e., global switch and local switch). Similar effects were obtained for P3 amplitude and for P3 latency for the local switch comparison. The only exception was the analysis of P3 latency for the global switch comparison, which reflected faster processing for the active than for the sedentary participants in the heterogeneous but not in the homogeneous trial blocks.

It is interesting to speculate as to why the physical activity effects were relatively broad with respect to task conditions and presumably cognitive processes in the present study whereas a recent meta-analysis suggested substantially larger physical activity effects for executive control processes (Colcombe and Kramer, 2003). One possible explanation concerns the nature and length of physical activity training. The studies examined in the Colcombe and Kramer (2003) meta-analysis were relatively short-term (3 years and less) randomized clinical trials with adults over the age of 55. On the other hand the present study has capitalized on self-directed physical activities over a lifetime (for the older adults). Therefore, it is conceivable that physical activity training effects that are obtained in later life are specific to the processes, such as executive control, that show the most substantial age-related declines (West, 1996).

References

Colcombe, S., Kramer, A.F., 2003. Fitness effects on the cognitive function of older adults: a meta-analytic study. Psychological Science 14, 125–130.

De Jong, R., 2001. Adult age differences in goal activation and goal maintenance. European Journal of Cognitive Psychology 13, 71–89.

Dustman, R.E., Emmerson, R.Y., Ruhling, R.O., Shearer, D.E., Steinhaus, L.A., Johnson, S.C., Bonekat, H.W., Shigeoka, J.W., 1990. Age and fitness effects on EEG, ERPs, visual sensitivity, and cognition. Neurobiology of Aging 11, 193–200.

Etnier, J.L., Salazar, W., Landers, D.M., Petruzzello, S.J., Han, M., Nowell, P., 1997. The influence of physical fitness and exercise upon cognitive functioning: a meta-analysis. Journal of Sport and Exercise Psychology 19, 249–277.

Hillman, C.H., Weiss, E.P., Hagberg, J.M., Hatfield, B.D., 2002. The relationship to age and cardiovascular fitness to cognitive and motor processes. Psychophysiology 39, 1–10.

Hillman, C.H., Belopolsky, A.V., Snook, E.M., Kramer, A.F., McAuley, E., 2004. Physical activity and executive control: implication for increased cognitive health during older adulthood. Research Quarterly for Exercise and Sport 75, 176–185.

Kramer, A.F., Hahn, S., Cohen, N.J., Banich, M.T., McAuley, E., Harrison, C.R., Chason, J., Vakil, E., Bardell, L., Boileau, R.A., Colcombe, A., 1999. Ageing, fitness and neurocognitive function. Nature 400, 418–419.

Kray, J., Lindenberger, U., 2000. Adult age differences in task switching. Psychology and Aging 15, 126–147.

Kray, J., Li, K.Z.H., Lindenberger, U., 2002. Age-related changes in task switching components: the role of uncertainty. Brain and Cognition 49, 363–381.

Lupinacci, N.S., Rikli, R.E., Jones, J., Ross, D., 1993. Age and physical activity effects on reaction time and digit symbol substitution performance in cognitively active adults. Research Quarterly for Exercise and Sport 64, 144–150.

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.

McCarthy, G., Wood, C.C., 1985. Scalp distributions of event-related potentials: an ambiguity associated with analysis of variance models. Electroencephalography and Clinical Neurophysiology 62, 203–208.

Meiran, N., 1996. Reconfiguration of processing mode prior to task performance. Journal of Experimental Psychology. Learning, Memory, and Cognition 22, 1423–1442.

Polich, J., 1997. EEG and ERP assessment of normal aging. Electroencephalography and Clinical Neurophysiology 104, 244–256.

Raz, N., 2000. Aging of the brain and its impact on cognitive performance: integration of structural and functional findings. In: Craik, F.I.M., Salthouse, T.A. (Eds.), The Handbook of Aging and Cognition, 2nd edition. Lawrence Erlbaum, Mahwah, NJ, pp. 1–90.

Rikli, R., Busch, S., 1986. Motor performance of women as a function of age and physical activity level. Journal of Gerontology 41, 645–649.

Rogers, R.D., Monsell, S., 1995. Costs of a predictable switch between simple cognitive tasks. Journal of Experimental Psychology. General 124, 207–231.

Semlitsch, H.V., Anderer, P., Schuster, P., Presslich, O., 1986. A solution for reliable and valid reduction of ocular artifacts, applied to the P3 ERP. Psychophysiology 23, 695–703.

Spirduso, W.W, Clifford, P., 1978. Replication of age and physical activity effects on reaction and movement time. Journal of Gerontology 33, 26–30.

West, R., 1996. An application of prefrontal cortex function theory to cognitive aging. Psychological Bulletin 120, 272–292.