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Lifelong physical activity and executive functions in older age assessed by memory based task switching

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ABSTRACT

Aging is accompanied by compromised executive control. Training studies point to beneficial effects of physical activity on executive functions. Here, we investigate the relationship between lifelong habitual physical activity (about 50 years) and switch ability in healthy seniors. Participants switched among three tasks in a memorized task sequence. Mixing costs for speed were lower in habitually active than low active participants whereas switch costs were not affected. Active participants revealed also lower mixing and switch costs for accuracy. These parameters were negatively correlated with the self-reported level of physical activity. The frontal CNV was smaller in the active than low active group. In contrast, in the target-locked ERPs active individuals showed an earlier P2, a larger frontocentral N2 and the typical pattern of smaller P3b in switch than non-switch trials relative to low-active individuals. These data suggest that lifelong physical activity is associated with faster recall of stimulus–response sets (P2), enhanced response selection during interference processing (N2) and working memory updating (P3b) leading to lower mixing and switch costs.

1. Introduction

Goal directed behavior is crucial for humans to act purposefully in changing environments. Executive functions enabling goal directed behavior are managed by dynamic neural systems interacting continuously with environmental requirements (Diamond, 2013; Miyake et al., 2000). Aging is associated with an impairment of some executive functions due to an age-related decline of those systems (Salthouse et al., 2003; West, 1996). However, a growing body of evidence suggests beneficial effects of physical activity and particularly aerobic exercise on executive functions in elderly (Colcombe and Kramer, 2003; Etnier and Chang, 2009; Hillman et al., 2008; Kramer and Erickson, 2007a,b; Gomez-Pinilla and Hillman, 2013; Guiney & Machado, 2013; Voelcker–Rehage and Niemann 2013, for meta-analyzes and reviews). Most of the reports analyzed effects of physical activity on executive functions in controlled intervention studies with interventions lasting up to 24 months (e.g. Colcombe et al., 2003; Hayes et al., 2013; Smith et al., 2010). On the other hand, there are some studies examining benefits of habitual but timely limited physical activity on executive functions in elderly using cross-sectional designs (Guiney and Machado, 2013 for review; Berchicci et al., 2013; Chang et al., 2010; Taddei et al., 2012; van Boxtel et al., 1997; Wendell et al., 2014). In sum, current research indicates that short- and middle-term physical activity counteracts age-related decline of executive functions (Colcombe et al., 2003, 2004, 2006; Draganski and May, 2008; Erickson et al., 2010, 2011; Flöel et al., 2010; Gomez-Pinilla and Hillman, 2013; Guiney and Machado, 2013; Hayes et al., 2013; Hillman et al., 2008; Voss et al., 2010; 2011; 2013; Weinstein et al., 2012). Therefore, long-term or even lifelong physical activity should attenuate age-related executive deficits to a much larger extent. However, there is to our knowledge no study which examined explicitly the relationship between lifelong (across several decades) physical activity and executive functions and their neural correlates in older individuals.

1.1. Task switching in older age

An important executive function, supporting goal-directed behavior is the ability to switch among different tasks while maintaining a goal. A tool to investigate and to separate different functional components during task switching is the memory based task switching paradigm (Rogers and Monsell, 1995). Task switching is not a unitary concept but consists of a number of cognitive components (Kiesel et al., 2010) which are differentially affected by age (Cepeda et al., 2001). Recent studies showed deterioration of specific sub-mechanisms involved in task switching in aging (Butler and Weywadt (2013)). For instance, age-related changes have been shown during task preparation and during maintaining multiple task sets in working memory (Cepeda, et al.,

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2001; Gajewski et al., 2010b; Kramer et al., 1999; Kray and Lindenberger, 2000; Mayr, 2001; Mayr and Liebscher, 2001; Meiran et al., 2001; Kray et al., 2004; Kray, 2006; West and Travers, 2008). Most researchers have been using an experimental task design consisting of blocks with single tasks only and blocks with task switching (mixed blocks). This allows to compute two types of switching costs: mixing (or global) and switching (or local) costs. Mixing costs are defined as performance differences between single task blocks and task repetition trials in mixed blocks. They are assumed to reflect updating and working memory processes (Kray et al., 2010) or the resolution of task ambiguity in the mixed blocks (Los, 1996; Mayr, 2001). Switching costs are defined as performance differences between switch and non-switch trials in mixed blocks. They are usually associated with interference between conflicting task sets (Allport et al., 1994; Kiesel et al., 2010). Mixing costs are usually larger in old than in young adults while switching costs are not (Cepeda et al., 2001; Eppinger et al., 2007; Karayanidis et al., 2011; Kramer et al., 1999; Kray and Lindenberger, 2000; Kray et al., 2005; Kray, 2006; Wasylyshyn et al., 2011 for review). The age-related increase in mixing costs is particularly evident in memory-based switching when the trial sequence has to be continuously maintained and the currently relevant task-set retrieved from memory (Kray and Lindenberger, 2000; Reimers and Maylor, 2005; Schapkin et al., 2014).

1.2. Aging effects on ERP components during task switching

Event related potentials (ERPs) offer deeper insights in the functional structure underlying task switching. Since ERPs have an excellent time resolution, they allow analyzing each function involved in task switching separately. In particular, task-set updating as reflected in the P3 component after cues is attenuated or delayed in older age (Friedman et al., 2007; Karayanidis et al., 2011; Kray et al., 2005; West, 2004; West and Travers, 2008). The findings regarding the CNV indicating anticipatory attention and task preparation are less consistent (Brunia and van Boxtel, 2001; Falkenstein et al., 2003; Walter et al., 1964). In some studies the CNV was reduced for older vs. young subjects (Sterr and Dean, 2008; West and Moore, 2005), but it has been also found to be larger in older than younger individuals in effortful conditions (i.e. under time pressure), suggesting stronger attention/preparation in elderly to maintain a sufficient level of performance (Berchicci et al., 2012; Goffaux et al., 2008; Karayanidis et al., 2011; Kray et al., 2005; Wild-Wall et al., 2007).

After the target onset the cognitive processes related to stimulus encoding, retrieval of S-R mapping and response selection and execution have to be completed. Each of these processes has been associated with a particular ERP component. In context of task switching the target-locked frontal P2, frontocentral N2 and parietal P3b have been studied. The P2 has been related to the retrieval of stimulus–response associations (Adrover–Roig and Barceló 2010; Gajewski et al., 2008; Kieffaber and Hetrick, 2005). Schapkin et al. (2014) found a larger P2 in older than younger participants in mixed blocks, whereas no age difference was found in single task blocks. According to the proposal of Finke et al. (2011) an increase of the P2 amplitude may reflect an additional effort of target processing in difficult conditions like switch trials. This was corroborated by a positive correlation between the P2 amplitude and RTs, suggesting the larger the P2 amplitude the slower the response. Moreover, Schapkin et al. (2014) found that the P2 latency was positively correlated both with reaction times and mixing costs in RTs in older participants. These findings support the idea of S–R retrieval of the P2 (Kieffaber and Hetrick, 2005) as the timing of the P2 peak is related to the timing of the correct response.

Following the P2 a large negative peak is visible, the frontocentral N2. The N2 was primarily associated with detection of mismatch and cognitive response monitoring (Folstein and Van Petten (2008); Hämmerer et al., 2014 for reviews), conflict processing (Van Veen, Carter 2002; Yeung and Cohen, 2006), and more generally to decision making (Ritter et al., 1979, 1982) and response selection i.e. the implementation of S–R mappings (Gajewski et al., 2008, 2010a; 2011). Response selection is intensified and delayed when response conflict has to be resolved, which is often reflected in enhanced and delayed N2 in switch vs. non-switch trials (Gajewski et al. 2010a).

The N2 is generally reduced and delayed with increasing age (Friedman, 2008; Hämmerer et al., 2014 for reviews), which suggests impaired response selection and/or compromised conflict resolution.

The subsequent target-locked P3b has been repeatedly described in context of task switching. The common pattern is a lower P3b-amplitude in switch vs. non-switch trials (Barceló et al., 2000; Gajewski and Falkenstein, 2011; Lorist et al., 2000; Rushworth et al., 2002). Moreover, the P3b is consistently larger in single task blocks than in mixed task blocks (Gajewski and Falkenstein, 2012; Jost et al., 2008; Karayanidis et al., 2011). Generally, the P3b amplitude decreases and its latency increases with age (e.g., Friedman, 2008; Polich, 1996).

1.3. Association between aerobic exercise and ERPs

It has been shown that not only performance in cognitive tasks but also some ERP components are modulated by physical activity (Gomez-Pinilla and Hillman, 2013; Guiney and Machado, 2013). For example Hillman et al. (2002) as well as Kamijo et al. (2010) showed that physically fit participants have smaller CNV amplitudes than non-fit individuals, suggesting generally less preparatory effort and higher preparation efficiency in physically active persons.

To our knowledge, only few studies investigated the N2 in older active versus inactive individuals. Taddei et al. (2012) who investigated young and older fencers and non-fencers in a go/no-go task reported faster reaction times, larger and earlier N2 both in young and in older fencers vs. non-fencers, supporting previous findings investigating young fencers only (Di Russo et al., 2006). In contrast, no association between exercise and the N2 was found in young adults subdivided in an aerobically active vs. low active group on the basis of maximal oxygen consumption (Themanson and Hillman, 2006a). These discrepant results may be due to different types of physical activity and/or different tasks.

Studies investigated associations between exercise and the P3b showed shorter latency and larger amplitude in physically active than low active adults in stimulus discrimination tasks (Polich and Lardon, 1997; Pontifex et al., 2009).

1.4. Association between aerobic exercise and ERPs during task switching

There are only few reports showing the relationship between physical activity and task switching ability using ERPs. Kamijo and Takeda (2010) using an alternative runs paradigm (Rogers and Monsell, 1995) found smaller switching costs in young physically active vs. inactive participants but no differences in the ERPs. Scisco, Leynes and Kang (2008) did not find any differences in task switch performance and ERPs between young physically fit and non-fit participants. The authors concluded that the relationship between greater cardiovascular fitness and improved cognitive function may emerge only later in adulthood. Indeed, Hillman et al. (2006) found lower mixing and switching costs and shorter latencies and larger amplitudes of the P3b in physically active than inactive older individuals. Themanson et al. (2006b) reported