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Long-term physical activity modulates brain processing of somatosensory stimuli: Evidence from young male twins

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ABSTRACT

Leisure-time physical activity is a key contributor to physical and mental health. Yet the role of physical activity in modulating cortical function is poorly known. We investigated whether precognitive sensory brain functions are associated with the level of physical activity. Physical activity history (3-yr-LTMET), physiological measures and somatosensory mismatch response (sMMR) in EEG were recorded in 32 young healthy twins. In all participants, 3-yr-LTMET correlated negatively with body fat%, $r = -0.77$ and positively with VO_{2max}, $r = 0.82$. The fat% and VO_{2max} differed between 15 physically active and 17 inactive participants. Trend toward larger sMMR was seen in inactive compared to active participants. This finding was significant in a pairwise comparison of 9 monozygotic twin pairs discordant for physical activity. Larger sMMR reflecting stronger synchronous neural activity may reveal diminished gating of precognitive somatosensory information in physically inactive healthy young men compared to the active ones possibly rendering them more vulnerable to somatosensory distractions from their surroundings.

1. Introduction

Physical activity has been demonstrated to be beneficial to human cognitive performance in cross-sectional and interventional studies, still neither the exact cognitive and executive functions nor the neural mechanisms responsible for improved cognitive performance are unequivocally identified (Voelcker-Rehage & Niemann, 2013). For instance, the cardiovascular functional response to vigorous long-term physical activity has been extensively studied while far less is known about the effects of physical activity on brain function in healthy adults. The previously detected association between good cardiovascular fitness and cognition in humans has implied that the improvements in cognitive task performance may typically be related to prefrontal cortex and other cortical structures (Hillman, Erickson, & Kramer, 2008) as opposed to subcortical structures. Most studies searching for associations between factors of physical fitness and cognition concentrate on elderly people (Voelcker-Rehage & Niemann, 2013; Erickson et al., 2011). This is conceivable because of the strong societal interest in many countries to search for the prerequisites of the late-life independence. Yet aging and diseases lead to mobility limitations, which may not be easily recognized and may still influence results, when studying relationships between physical fitness and cognition (Wilkie, Peat, Thomas, & Croft, 2006). The connections between physical exercise and cognitive function especially in the elderly have recently been carefully reviewed (Voelcker-Rehage & Niemann, 2013). Most of these studies apply cognitively delivered responses to various tasks such as button presses or answers in questionnaires but the underlying brain functions are inadequately known.

Sensitive assessments of the changes in cortical function can be performed using EEG-based techniques such as evoked potentials (EP). The mismatch negativity (MMN), a well-defined component of the auditory evoked potential, is generated by a cortical automatic change-detection process. MMN is extensively studied in auditory modality where it is elicited by any discernible auditory change when the ongoing auditory input is found to differ from the preceding auditory stimulus (Näätänen, Paavilainen, Rinne, &

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Alho, 2007). Auditory MMN is generated by both temporal cortices and the frontal cortex (Näätänen & Kähkönen, 2009). Less frequently studied somatosensory mismatch response (sMMR) is a corresponding change detection mechanism while the brain is processing somatosensory ascending information (Akatsuka et al., 2005; Kekoni et al., 1997). Characteristics of sMMR are sparsely studied, however, both early and late components to sensory stimulus deviance have been identified (Restuccia et al., 2009) and we recently detected differences between young and elderly adults (Strömmer, Tarkka, & Astikainen, 2014). The automatic change detection of the somatosensory stimulus likely occurs, at least in part, in the SI and SII sensory representation areas of the stimulated body part. Various types of stimuli can elicit sMMR including electrical and vibratory stimuli (Akatsuka, Wasaka, Nakata, Kida, & Kakigi, 2007; Spackman, Boyd, & Towell, 2007), and in all stimulus types violations to previous stimulus array need to be presented. Regardless of the stimulus mode deviance detection is present in the somatosensory system in healthy individuals.

Increased physical activity is known to modulate corticospinal neural function in addition to changes in muscle biochemistry and cardiovascular function (Carroll, Selvanayagam, Riek, & Semmler, 2011). We selected a cohort of young twin males to see whether dissimilarities in physical activity, when chronic diseases are uncommon and medications or possible prodromal phases are not yet present, are associated with modulation in brain electrophysiology. Our specific aim was to investigate whether the processing of precognitive somatosensory input is associated with long-term physical activity in young healthy men. We chose monozygotic twin pairs discordant for physical activity to adjust for known and unknown confounders of the association between physical activity and somatosensory brain processing. First we confirmed that our subjects differed in physical activity history. It is conceivable that the ascending information from the body is enhanced during physical exercise and thus we hypothesized that differences in sMMR may exist between those who habitually exercise and those who do not.

2. Methods

2.1. Subjects

Participants of the present study, a segment of FITFATTWIN study, were 32 healthy males (15 active and 17 inactive), specifically 16 monozygotic pairs, among whom 9 pairs were discordant for leisure-time physical activity during past 3 years (active and inactive co-twin, see detailed criterion for discordance (Rottensteiner et al., 2015). The remaining 7 pairs were divided into active and inactive individuals according to the same criteria however, both members of the twin pair were either active or inactive. Participants for the FITFATTWIN study were initially identified from the FinnTwin16Cohort, which is a population based, longitudinal study of Finnish twins born between October 1974 and December 1979 (Kaprio, Pulkkinen, & Rose, 2002). Selection of the twin pairs to the present study was performed on the basis of the data on the web-based questionnaire, telephone interview, interview at the laboratory and medical examination at the laboratory. More details of the selection procedure can be found in (Rottensteiner et al., 2015). The participants of the present study participated in comprehensive two day FITFATTWIN clinical study measurements.

All experimental procedures and study protocols were approved by the Ethical Review Board for Human Research of the Central Finland Health Care District (9/29/2011) and the study was conducted in accordance with the Declaration of Helsinki. All participants volunteered and provided a written informed consent.

2.2. Physical activity estimation and physiological measures

In this study physical activity levels and pairwise discordance was based on structured retrospective physical activity interview (Kujala, Kaprio, Sarna, & Koskenvuo, 1998; Waller, Kaprio, & Kujala, 2008; Leskinen et al., 2009) covering leisure-time physical activity, including commuting activity, at one-year intervals over the past six years. The leisure-time physical activity volume was quantified as a leisure-time MET index. The leisure-time physical activity was calculated as frequency (per month) $\times$ duration (min) $\times$ intensity (MET) and commuting activity as frequency as five times per week $\times$ duration (min) $\times$ intensity of 4 METs, and were expressed as the sum-score of MET hours/day (MET index). The mean leisure-time MET index during the past three years (3-yr-LTMET index as MET hours/day) was calculated and used as a criterion to assess leisure-time physical activity level. The difference between the active vs. inactive participants in leisure-time physical activity for the past 3 years was $\geq$1 METh/day. The most common types of leisure-time physical activity reported were jogging and walking.

Weight, height and waist circumference (midway between the spina iliaca superior and the lower rib margin) were measured, body mass index (BMI) was calculated, maximal oxygen uptake (VO_{2max}) was measured by a maximal exercise test using a bicycle ergometer, and the whole body composition was determined after an overnight fast using dual-energy X-ray absorptiometry (DXA Prodigy; GE Lunar Corp., Madison, Wisconsin), for more details (Rottensteiner et al., 2015). BMI, waist circumference, fat% and VO_{2max} were retained for further analysis.

2.3. Somatosensory mismatch response recording

sMMR was elicited by precognitive location deviance detection. Somato-sensory stimuli were delivered through flexible metal ring electrodes (stimulating cathode around the proximal phalanx and anode around the distal phalanx) to the left index and little fingers (Digitimer Ltd., model DS7A, Welvyn Garden City, UK). Conductive paste was used to reduce impedance. First, standard stimuli were delivered to the index finger and deviant stimuli to the little finger. Second, standard stimuli were delivered to the little finger and deviant stimuli to the index finger. Each stimulus duration was 200 μs and the stimulus intensity was set twice the individual sensory threshold. In each condition, 1000 stimuli were delivered, 10% of them were deviants delivered in a random order. The interstimulus interval (ISI) was 600 ms. Participants listened to a radio play paying no attention to the electrical stimuli. After testing they were asked several questions of the play to ensure they had listened to it. Both twins were recorded on the same day. Continuous EEG was recorded with 128-channel sensor net (Electrical Geodesics, Inc., Portland, Oregon) and analyzed using average reference. The sampling rate was 1000 Hz using 0.1–400 Hz filters.

The EEG data was bandpass filtered (in a range 0.1–25 Hz) and segmented to 500 ms epochs (100 ms pre-stimulus for baseline, 400 ms post-stimulus interval). Epochs containing artifacts were rejected, where epochs with high absolute amplitude potential shifts (at channels selected for further analysis) and eye-blink/movement artifacts (detected from the frontal, electro-oculographic channels) were selected for rejection. Noise-free epochs were baseline corrected and averaged to form the deviant wave form and the same amount of standard stimuli as the individual's deviant stimuli to form the standard wave form for each individual. Standard stimuli selected for averaging were randomly picked from remaining subset excluding first 20 and last 20, to avoid adaptation and habituation effects. The minimum number of accepted deviants was 42 per participant to be included in the average and to further analyses (individual deviant mean 87, range 42–100). Then a difference wave form was calculated by