Avoiding sedentary behaviors requires more cortical resources than avoiding physical activity: An EEG study

Abbreviated Title: Escaping the innate attractive force of sedentary behaviors

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Abstract

Why do individuals fail to exercise regularly despite knowledge of the risks associated with physical inactivity? Automatic processes regulating exercise behaviors may partly explain this paradox. However, these processes have only been investigated with purely behavioral paradigms. Here, using electroencephalography, we investigated the cortical activity underlying automatic approach and avoidance tendencies toward stimuli depicting physical activity and sedentary behaviors in 29 young adults who were physically active (n=14) or physically inactive but with the intention of becoming physically active (n=15). Behavioral results showed faster reactions when approaching physical activity compared to sedentary behaviors, but faster reactions when avoiding sedentary behaviors compared to physical activity. These faster reactions were more pronounced in physically active compared to inactive individuals and were associated with changes during sensory integration (earlier onset latency and larger positive deflection of the stimulus-locked lateralized readiness potentials) but not during motor preparation (no effect on the response-locked lateralized readiness potentials). Faster reactions when avoiding sedentary behaviors compared to physical activity were also associated with higher conflict monitoring (larger early and late N1 event-related potentials) and higher inhibition (larger N2 event-related potentials), irrespective of the usual level of physical activity. These results suggested that additional cortical resources were required to counteract an innate tendency to approach sedentary behaviors.

Significance statement

Our reactions to stimuli related to physical activity and sedentary behaviors depend on interactions between conscious intentions and automatic processes. For the first time, we investigated the cortical activity underlying automatic reactions in exercise behavior. Our results revealed that faster reactions to approach physical activity and avoid sedentary behaviors were explained by brain processes occurring during sensory integration, not during motor preparation. However, avoiding stimuli depicting sedentary behaviors required more cortical resources than avoiding stimuli depicting physical activity. These additional cortical resources were recruited to monitor cortical conflicts and increase cortical inhibition of automatic reactions. Contrary to behavioral results, these findings suggested that additional brain resources are required to escape an innate attraction toward sedentary behaviors and increase our level of physical activity.

Key points

- Individuals, especially the physical active ones, showed faster reactions when approaching physical activity compared to sedentary behaviors, but faster reactions when avoiding sedentary behaviors compared to physical activity.
- These faster reactions were associated with changes during sensory integration, but not during motor preparation.
- However, faster reactions when avoiding sedentary behaviors compared to physical activity were associated with higher conflict monitoring and higher inhibition, irrespective of the usual level of physical activity.
- These findings suggest that brain resources are required to escape an innate attraction toward sedentary behaviors and increase our level of physical activity.

Introduction

Why do we fail to exercise regularly (Kohl et al., 2012) despite the negative effects of physical inactivity on health (e.g., Lee et al., 2012; Ekelund et al., 2016)? Automatic processes may partly explain this paradox. Exercise behavior is regulated by controlled and automatic processes (Strack and Deutsch, 2004; Moors and De Houwer, 2006). Controlled processes are initiated intentionally, require cognitive resources, and operate within conscious awareness. Automatic processes are initiated unintentionally, tax cognitive resources to a much lesser extent, occur outside conscious awareness, and can be problematic when they come into conflict with controlled processes (Strack and Deutsch, 2004; Marteau et al., 2012). For example, the detection of an opportunity for being sedentary can automatically elicit a drive competing with the conscious intention to adopt a physically active behavior, thereby disrupting or preventing its implementation.

Automatic processes have been investigated using reaction-time tasks such as approach-avoidance tasks where individuals are instructed to approach or avoid a stimulus as fast as possible (Mogg et al., 2005; Cousijn et al., 2011; Zhou et al., 2012; Ernst et al., 2014; Wiers et al., 2014). Automatic approach tendencies toward stimuli depicting physical activity and sedentary behaviors have been shown to positively and negatively predict physical activity, respectively (Cheval et al., 2014; Cheval et al., 2015). In addition, these studies showed a higher tendency to approach than to avoid stimuli depicting physical activity and vice versa with sedentary behaviors (Cheval et al., 2014; Cheval et al., 2015; Cheval et al., 2016), thereby suggesting that automatic processes support physical activity. These behavioral results are inconsistent with the fact that most people fail to exercise regularly despite the intention to be physically active (Rhodes and Dickau, 2012; Rhodes and Bruijn, 2013). Investigating the neural mechanisms underlying these reaction-time differences is necessary to understand this discrepancy.

Electroencephalography (EEG) provides the millisecond-range resolution required to capture the neural activity underlying the reaction-time differences used to investigate automatic approach and avoidance tendencies. Lateralized Readiness Potentials (LRP) are used to capture the chronometry of the brain processes underlying an action (Gratton et al., 1988; Smulders and Miller, 2012). Particularly, stimulus-locked LRP (S-LRP) reflect sensory integration and response-locked LRP (R-LRP) reflect the subsequent processes involved in motor preparation. Event-Related Potentials (ERP) can be used to investigate the neural resources involved in a behavior. Particularly, the P1 reflects the automatic allocation of attention toward relevant emotional stimuli (Smith et al., 2003; Keus et al., 2005; Olofsson et al., 2008), early N1 reflects conflict monitoring (van Veen et al., 2001; Botvinick et al., 2004; Kerns et al., 2004), late N1 reflects enhanced perceptual processing during conflict (Vogel and Luck, 2000; Kirmizi-Alsan et al., 2006; Ernst et al., 2013), and the N2 reflects the inhibition of automatic reactions (van Boxtel et al., 2001; Folstein and Van Petten, 2008).

Here, we investigated the neural mechanisms underlying automatic approach and avoidance reactions toward physical activity and sedentary behaviors. We hypothesized a stronger tendency to approach physical activity than sedentary behaviors and to avoid sedentary behaviors than physical activity (Hypothesis 1a). We expected these tendencies to be stronger in individuals who successfully implement their intention to be physically active (Hypothesis 1b). We further hypothesized that this effect of stimuli on reaction time results from altered processes during the sensory integration of these visual stimuli, not during motor preparation. Specifically, as all the participants of this study intended to be physically active, we hypothesized that sensory integration is shorter (i.e., larger positive deflection and earlier LRP onset latency) when participants are asked to approach physical activity and avoid sedentary behaviors compared to approach sedentary behaviors and avoid physical activity (Hypothesis 2). Additionally, consistent with recent conceptual and review articles suggesting an innate tendency to conserve energy and avoid unnecessary physical exertion (Lieberman, 2015; Lee et al., 2016; Cheval et al., 2018), shorter reaction times to approach physical activity and avoid sedentary behaviors should require more cortical resources. Accordingly, we hypothesized higher attentional processing (larger P1 and late N1 amplitudes), conflict monitoring (larger early N1 and late N1 amplitudes), and inhibition (larger N2 amplitude) when approaching physical activity compared to sedentary behaviors and when avoiding sedentary behaviors compared to physical activity (Hypothesis 3). We expected these cortical outcomes to be more pronounced in individuals who successfully implement their intention to be physically active (Hypothesis 4).

Materials and Methods

Participants

Participants were invited to take part in the study through posters in the University. To be included in the study, participants had to be right-handed according to the Edinburgh Handedness Inventory (Oldfield, 1971) and in the preparation (i.e., low level of physical activity with a strong intention to start) or maintenance stage of physical activity (i.e., high level of physical activity for at least 6 months) according to the stage of change questionnaire for exercise behavior (Marcus et al., 1992). Participants with a history of psychiatric, neurological, or severe mental disorders, or taking psychotropic medication or illicit drugs at the time of the study were excluded. Thirty-seven young volunteers met the eligibility criteria. Eight participants were removed from the analyses due to e-prime and EEG data recording malfunctions resulting in a final sample of 29 participants (16 females, 13 males; age = 22.8 ± 3.0 years; body mass index = 21.8 ± 3.1 kg/m^2) including 14 physically active participants (i.e., maintenance stage) and 15 physically inactive participants with the intention to be physically active (i.e., preparation stage). All participants received a 20 CHF voucher. The University of Geneva Ethics committee approved this research and informed consent process.

Pilot studies

Pilot study 1: Choice of the pictures depicting physical activity and sedentary behaviors

A first pilot study identified the pictures depicting physical activity and sedentary behaviors to be included in the approach-avoidance task. Thirty-two participants were asked to rate the extent to which 24 pictures expressed movement and active lifestyle (1 = not at all, 7 = a lot) on one hand, and rest and sedentary lifestyle on the other hand. To minimize biases associated with pictures depicting real people, a designer drew pictograms to represent physical activity and sedentary behaviors. The size of the pictures was 200 × 250 pixels. For each picture, the "rest and sedentary lifestyle" score was subtracted from the "movement and active lifestyle" score. The ten pictures with the largest positive and negative differences were chosen as the stimuli depicting physical activity and sedentary behaviors in the main experiment, respectively. Statistical analyses confirmed that the five pictures depicting physical activity showed higher physical activity scores (M = 5.97, SD = 0.88) than sedentary behavior scores (M = 1.85, SD = 0.69, $t(31) = -15.33$, $p < 0.001$) and that the five pictures depicting sedentary behaviors showed higher sedentary behavior scores (M = 5.30, SD = 1.02) than the physical activity scores (M = 2.15, SD = 0.89, $t(31) = -10.23$, $p < 0.001$).

Pilot Study 2: Validation of the neutral pictures

A second pilot study tested the effect of the neutral pictures. Thirty-nine participants were asked to rate the extent to which 30 pictures expressed rest and sedentary lifestyle versus movement and active lifestyle on a 7-point bipolar response scale (i.e., -3 to +3). We used the 10 pictures selected in the first pilot study and the 20 neutral pictures (the pictures based on squares and circles; Figure 1). Statistical analyses confirmed a significant effect of the type of pictures (i.e., physical activity vs. sedentary behaviors vs. neutral, $F(2, 76) = 658.14$, $p < 0.001$). As expected, post-hoc analyses revealed that pictures depicting physical activity were more strongly related to movement and active lifestyle than neutral pictures (M = 4.66 vs. 2.46, $p < 0.001$), and pictures depicting sedentary behaviors were more strongly related to rest and sedentary lifestyle than neutral pictures (M=-2.21, $p < 0.001$). Finally, neutral pictures were not significantly different from zero ($p = 0.153$).

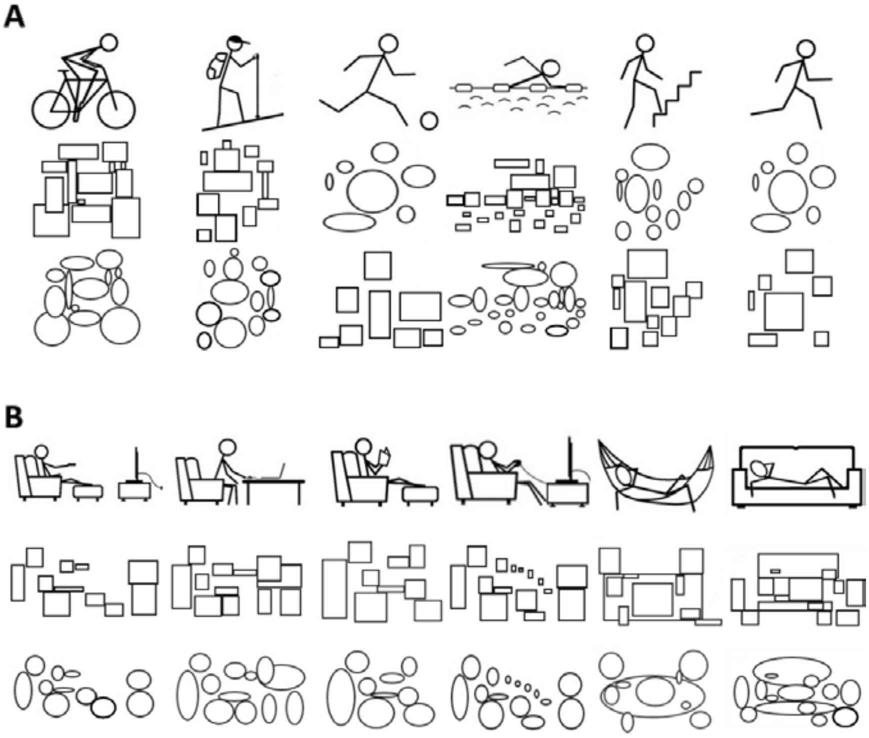

Figure 1. Pictures in the approach-avoidance task. A. Images depicting physical activity, and neutral stimuli built with circles and squares based on the amount of information (i.e., same number and same size) in the pictures depicting physical activity. **B.** Images depicting sedentary behaviors, and neutral stimuli built with circles and squares based on the amount of information (i.e., same number and same size) in the pictures depicting sedentary behaviors. Pictures were selected based on the results of two pilot studies.

Approach-Avoidance Task

A contextual approach-avoidance task was used to measure automatic approach and avoidance tendencies toward physical activity and sedentary behaviors (Cheval et al., 2014; Cheval et al., 2015; Figure 2). Participants were asked to move a manikin on the screen “toward” (approach condition) and “away” (avoidance condition) from images depicting physical activity and sedentary behaviors (Figure 1) by pressing keys on a keyboard. Each trial started with a black fixation cross presented randomly for 250 to 750 ms in the center of the screen with a white background. Then, the manikin appeared in the upper or lower half of the screen. Concurrently, a stimulus depicting ‘movement and active lifestyle’ (i.e., physical activity) or “rest and sedentary lifestyle” (i.e., sedentary behavior) was presented in the center of the screen. Participants quickly moved the human figure “toward” a picture (approach) depicting physical activity and “away” from a picture (avoidance) depicting sedentary behaviors, or vice versa. After seeing the manikin in its new position for 500 ms, the screen was cleared. In case of incorrect response, an error feedback (i.e., a cross) appeared at the center of the screen.

A neutral approach-avoidance task was used as a control. In this task, the stimuli depicting physical activity and sedentary behaviors were replaced by pictures with circles or squares matching the number and size of information in the original pictures (Figure 1). Participants were asked to quickly move the manikin “toward” pictures with circles and “away” from pictures with squares, or vice versa. For half of the participants, the neutral stimuli with circles were built based on the stimuli depicting physical activity and the neutral stimuli with squares were built based on the stimuli depicting sedentary behaviors. For the other half of participants, it was the opposite. The neutral approach-avoidance task provided the baseline approach and avoidance tendencies of each individual.

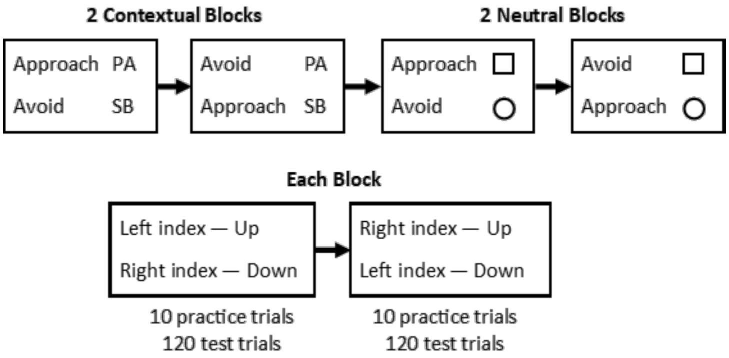

Figure 2. Description of the approach-avoidance task procedure. A. Description of the manikin task. Participants were asked to 1) approach stimuli depicting physical activity (120 trials), 2) avoid stimuli depicting sedentary behaviors (120 trials), 3) avoid stimuli depicting physical activity (120 trials), 4) approach stimuli depicting sedentary behaviors. Here, we display an example of a trial in which participants were asked to approach a stimulus depicting physical activity. **B.** Description of the procedure of the approach-avoidance task. The contextual and the neutral approach-avoidance task, the order of the blocks, and the order of the finger used are counterbalanced across participants. PA = physical activity; SB = sedentary behaviors.

Experimental Design

Sixty-four participants completed an online questionnaire measuring their stage of change for exercise behavior. This questionnaire was emailed to the participants with an identification code randomly created. Participants who met the eligibility criteria were invited to the laboratory and filled the informed consent form and Edinburgh Handedness Inventory (Oldfield, 1971). Then, they sat in front of a computer screen (1280 × 1024 pixels) in a sound-attenuated room, were equipped with EEG recording electrodes, and performed the approach-avoidance task.

The contextual approach-avoidance task was performed in two blocks (Figure 1). In each block, the participants performed 10 practice trials and 240 test trials. During test trials, each of the 10 pictures appeared 12 times at the top and 12 times at the bottom of the screen. In one block, participants were instructed to approach pictures depicting physical activity and avoid pictures depicting sedentary behaviors. In the other block, they were instructed to do the opposite. To be able to compute the LRP, the 240 test trials were divided in two parts. In the first part, participants were asked to press the "8" key with their left index to move the manikin up and the "2" key with their right index to move the manikin down. In the second part, participants were asked to press the "8" key with their right index and the "2" key with their left index. The neutral approach-avoidance task was performed in two additional blocks. The number of practice and test trials was identical as in the contextual approach-avoidance task. The contextual and the neutral approach-avoidance task, the order of the blocks, and the order of the finger used were counterbalanced across participants, and the stimuli appeared in a random order within blocks (Figure 1).

Physical Activity

Stage of Change

The stage of change for exercise and participation in the physical activity questionnaire (Marcus et al., 1992) was used to assess participants' readiness to change their exercise behavior and involvement in the exercise behavior change process on a five-item scale corresponding to the five stages of change for exercise: The maintenance ("I exercise regularity and have done so for longer than 6 months"), action ("I exercise regularity but have done so far less than 6 months"), preparation ("I currently exercise some but not regularly but I have a strong intention to start"), contemplation ("I currently do not exercise but I have been thinking about starting to exercise in the next 6 months"), and pre-contemplation stage ("I currently do not exercise and I do not intend to start in the next 6 months).

Usual Level of Physical Activity
The usual level of physical activity was assessed using the adapted version of the International Physical Activity Questionnaire (IPAQ; Booth, 2000; Craig et al., 2003) assessing physical activity undertook across leisure time during a week. The specific types of activity were classified into three categories: Walking, moderate-intensity activities, and vigorous-intensity activities. The usual level of moderate-to-vigorous physical activity (in min per week) was used in a sensitivity analysis.

EEG Acquisition
The electrical signal of the brain was recorded using a 64-channels Biosemi Active-Two system (Amsterdam, Netherlands) with AG/AgCl electrodes positioned according to the extended 10–20 system. To capture eye movements and blinks, four additional flat electrodes were positioned on the outer canthi of the eyes, and above and under the right eye. A reference electrode was positioned on the earlobe. Each active electrode was associated with an impedance value, which we kept below 20 kΩ for each participant. The EEG was continuously recorded with a sampling rate of 1024 Hz.

EEG Processing
Standard processing of EEG data was performed off-line using the software Brain Vision Analyzer, version 2 (Brain Products, Gilching, Germany). Data was down-sampled to 512 Hz. ERPs were segmented from 200 ms prior to 1000 ms after stimulus onset. Electrodes that were noisy over the entire recording were interpolated using a spherical spline (Perrin et al., 1989)2.5% of the electrodes). A baseline correction was applied using the 200 ms prestimulus period. ERPs and LRPs were obtained by averaging the trials for each condition on the data that was filtered with a low-cutoff at 0.1 Hz and a high-cutoff at 30 Hz. Ocular movements and blink correction was performed on the EEG using the implemented standard algorithm (Gratton et al., 1983). Trials with other artefacts were removed using a semi-automatic procedure (amplitude allowed: -100 to +100 µV) resulting in a total 11% of removed trials.

EEG Metrics
Event-Related Potentials
The P1 ERP peaks around 100–130 ms post-stimulus over the lateral occipital electrodes, reflecting the joint neural activity in the extrastriate cortex (Luck, 2014). P1 is thought to reflect automatic attention allocation toward relevant emotional stimuli (Smith et al., 2003; Keus et al., 2005; Olofsson et al., 2008). The N1 ERP can be divided in several subcomponents, with earlier effects appearing on anterior electrode sites and later effects appearing on posterior electrodes (Luck, 2005; Ernst et al., 2013). The early N1 peaks around 100–150 ms post-stimulus over the anterior electrodes and has been linked to the activity of the anterior cingulate cortex (Mulert et al., 2001; Mulert et al., 2003). It has been suggested that this activity occurs during incentive conditions, with higher incentives leading to higher anterior N1 amplitudes (Mulert et al., 2005). Moreover, the activity of the anterior cingulate cortex has been linked to conflict monitoring (van Veen et al., 2001; Botvinick et al., 2004; Kerns et al., 2004). The late

N1 peaks around 150–200 ms post-stimulus over the posterior electrodes revealing activity in the lateral occipital cortex (Luck, 2014). This activity is elicited by discriminative processing in spatial attention tasks (Vogel and Luck, 2000) leading to enhanced perceptual processing of relevant stimuli. In the context of approach-avoidance tasks, the late N1 has often been elicited in conflict-related conditions (Kirmizi-Alsan et al., 2006; Ernst et al., 2013). The fronto-central N2, which peaks around 200–400 ms post-stimulus (Ernst et al., 2013), is thought to reflect inhibition of automatic reactions (van Boxtel et al., 2001; Folstein and Van Petten, 2008).

Lateralized Readiness Potentials

The LRP is a movement-related brain potential that reflects hand-specific motor preparation (Masaki et al., 2000; Leppänen et al., 2003) and can detect subtle activations that do not necessarily lead to an overt motor response (Dehaene et al., 1998). LRP can be assessed to capture the chronometry of the brain processes underlying an action, and to infer the cognitive demand related to this action (Smulders and Miller, 2012). LRP can be divided into two components. The stimulus-locked LRP (S-LRP) reflects sensory integration and the response-locked LRP (R-LRP) reflects the subsequent processes involved in motor preparation (Mordkoff and Gianaros, 2000; Rinkenauer et al., 2004; Luck and Kappenman, 2011). In a choice reaction time task involving both upper limbs, positive deflections indicate response preparation of the correct limb, whereas negative deflections indicate a short-lived covert activation of the incorrect limb (Dehaene et al., 1998). In other words, in incongruent conditions (i.e., when the intended response hampers the selection of the required response), the stimulus induces a covert motor activation that mismatches with the overt response required by the task, leading to a competition between responses. As described above, the LRP can be either stimulus-locked (i.e., measured with respect to the stimulus onset; S–LRP) or response-locked (i.e., measured with respect to the manual response; R–LRP) (Rinkenauer et al., 2004; Keus et al., 2005). S–LRP reflects the earlier processing of response preparation, which are related to sensory integration (e.g., stimulus-evaluation and response-selection processes), whereas R–LRP reflects the processes involved in motor preparation (Rinkenauer et al., 2004; Huang and Luo, 2006; Broadway, 2012; Noorbaloochi et al., 2015).

LRPs were computed in each condition using the double subtraction technique. The signal from the electrodes contralateral to the response was averaged in each participant (C3: Left hemisphere and C4: Right hemisphere). Then, the following formula was applied:

$$\left(C3'(t)_{right\ hand} - C4'(t)_{right\ hand}\right) - \left(C3'(t)_{left\ hand} - C4'(t)_{left\ hand}\right)$$

where $C3'(t)$ and $C4'(t)$ are the potentials at $C3'$ and $C4'$ scalp sites, respectively, for multiple time points (Smulders and Miller, 2012). The difference between contralateral and ipsilateral potentials on these electrodes allowed the identification of a specific response (right or left hand) for each condition. For the LRPs relative to stimulus onset, epochs were calibrated 200 ms before and 1500 ms after stimulus onset. For the LRPs relative to response onset, epochs were calibrated 500 ms before and 100 ms after response onset.

Statistical Analyses

Behavior

Incorrect responses and responses below 150 ms and above 1500 ms were excluded as recommended by Krieglmeyer and Deutsch (2010). The relative reaction times to approach (or avoid) stimuli depicting sedentary behaviors were calculated by subtracting the median reaction time of the participant when approaching (or avoiding) neutral stimuli from each reaction time when approaching (or avoiding) stimuli depicting sedentary behaviors. This subtraction was

applied to control for the reaction time associated with the tendency to approach and avoid neutral stimuli. The same procedure was applied to the stimuli depicting physical activity.
Behavioral data were analyzed with linear mixed models, which take into account both the nested (multiple measurements within a single individual) and crossed (participants and stimuli) random structure of the data, thereby providing accurate parameter estimates with acceptable type I error rates (Boisgontier and Cheval, 2016). Moreover, linear mixed models avoid data averaging which keeps the variability of the responses within each condition and increases power compared with traditional approaches such as the analysis of variance (ANOVA) (Judd et al., 2017). We built a model using the lme4 and lmerTest package of the R software (Kuznetsova et al., 2017) and specified both participants and stimuli as random factors. Action (-0.5 for approach trials; 0.5 for avoidance trials), Stimuli (-0.5 for stimuli depicting physical activity; 0.5 for stimuli depicting sedentary behaviors), Stage of change for exercise (-0.5 for physically inactive individuals; 0.5 for physically active individuals), and their interactions were included as fixed factors in the model. A random error component were included for Action and Stimuli. An estimate of the effect size was reported using the conditional pseudo R^2 computed using the MuMin package of the R software (Barton, 2009).

Event-Related Potentials

Because this study was the first to use ERPs to investigate approach and avoidance reactions toward physical activity and sedentary behaviors stimuli, it was not possible to formulate specific a-priori hypotheses on the spatiotemporal distribution of the potential effects. Therefore, we performed a whole-scalp analysis (64 electrodes) from 0 (stimulus appearance) to 800 ms using a cluster-mass permutation test (Maris and Oostenveld, 2007), which is appropriate for exploratory analyses and delimiting effect boundaries when little guidance is provided by previous research (Manly, 1997; Groppe et al., 2011; Luque et al., 2017). To fit the analysis with the experimental design and use resampling methods, we perform F-tests of repeated measures ANOVA and the null distribution was computed using permutations of the reduced residuals (Kherad-Pajouh and Renaud, 2015). The family-wise error rate was controlled using the cluster-mass test (Maris and Oostenveld, 2007), with a threshold set at the 95% quantile of the F statistics. For the cluster-mass test, we defined the spatial neighborhoods between electrodes using an adjacency matrix. Each pair of electrodes with a Euclidian distance smaller than delta = 35mm was defined as adjacent, where delta is the smallest value such that the graph created by the adjacency matrix is connected.

Lateralized Readiness Potentials

The amplitude LRP were analyzed with a 2 (Action: approach vs. avoidance) × 2 (Stimuli: physical activity vs. sedentary behaviors) × 2 (Stage of change for exercise: physically inactive vs. for physically active) mixed-subject design analysis of variance (ANOVA). LRP outcomes were analyzed using ANOVA because the use of linear mixed models has not been implemented for LRP analyses yet. We used the relative signal, i.e., the difference between the amplitude of the stimulus category and the neutral stimuli. The LRP onsets were measured and analyzed by applying the jackknife-based procedure (Ulrich and Miller, 2001). LRP onset measures were submitted to ANOVA with F-values corrected as follows:
$Fc = F/(n-1)2$,where Fc is the corrected F-value and n the number of participants (Ulrich and Miller, 2001).The Greenhouse-Geisser epsilon correction was applied to adjust the degrees of freedom of the F-ratio when appropriate. LRP measurements (amplitude and onset latencies) were computed based on the average of left and right manual responses, with respect to the experimental condition.

Sensitivity Analyses

To examine the robustness of the simple effects of approaching rather than avoiding sedentary behaviors and physical activity stimuli, we performed three sensitivity analyses: using only circle-based pictures as neutral stimuli, using only square-based pictures as neutral stimuli, and replacing stage of change for exercise by the usual level of physical activity as measured by the IPAQ.

Data and Code Accessibility

All data and code are available in Zenodo (doi: 10.5281/zenodo.1169140)

Results

Descriptive results

Results showed that participants in the preparation stage self-reported lower usual level of physical activity than participants in the maintenance stage of physical activity (93.6 ± 74.0 vs. 330.0 ± 160.0 minutes per week, $p < 0.001$). Body mass index (22.3 ± 3.7 vs. 21.3 ± 2.3 kg/m^2, $p = 0.415$), age (23.4 ± 3.1 vs. 22.2 ± 2.9 years, $p = 0.276$), and sex (8 females and 6 males vs. 6 males and 4 females, $p = 0.999$) were not significantly different across groups.

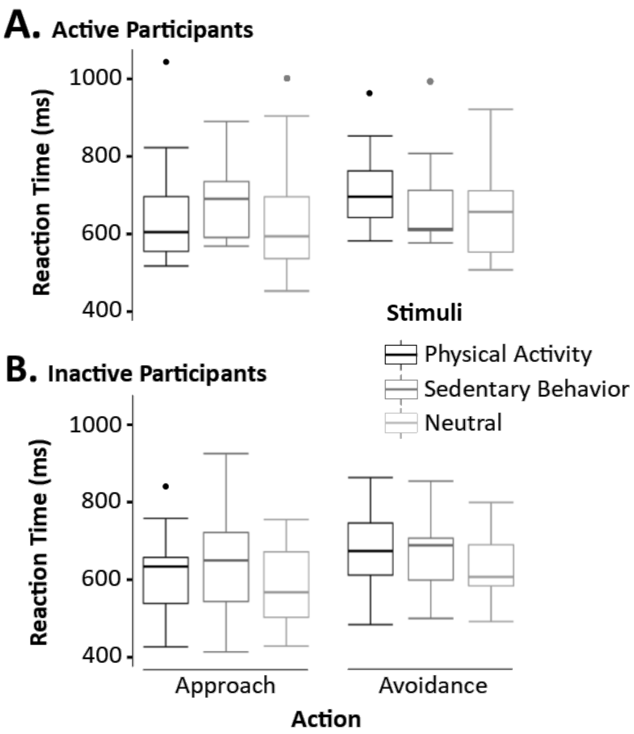

Figure 3. Descriptive results showing reaction time to approach and avoid stimuli depicting physical activity, sedentary behaviors and neutral stimuli in physically active (A) and inactive participants (B). The middle of the boxplot = median, lower hinge = 25% quantile, upper hinge = 75% quantile, lower whisker = smallest observation greater than or equal to lower hinge – 1.5 × interquartile range, upper whisker = largest observation less than or equal to upper hinge + 1.5 × interquartile range.

Behavior

Results of the linear mixed models (Table 1) showed no significant main effects of action (p = 0.982), stimuli (p = 0.419), and stage of change for exercise (p = 0.780). However, the two-way interaction between action and stimuli was significant (b = -62.69, $p < 0.001$). Simple effect tests showed that participants approached stimuli depicting physical activity faster than sedentary behaviors (b = 37.66, $p < 0.001$). Conversely, participants avoided physical activity slower than sedentary behaviors (b = -25.03, p = 0.007). Additionally, results showed that participants were faster at approaching compared to avoiding physical activity (b = 31.21, p < 0.001), whereas they were faster at avoiding compared to approaching sedentary behaviors (b = -31.47, p < 0.001). The three-way interaction between action, stimuli, and stage of change for exercise was significant (b = -54.30, p < 0.001). As illustrated in Figures 3 and 4, results showed that the two-way interaction between action and stimuli was significantly more pronounced in physically active (b = -89.88, p < 0.001) than inactive participants (b = -35.58, p < 0.001). In this model, the variables under consideration explained 14.9% of the variance in the reaction time.

Fixed Effects	b	SE	p-value
Intercept	87.00	13.50	< 0.001
Approach-avoidance[1]	-0.13	5.81	0.982
Stimuli[2]	6.32	7.58	0.419
Action (approach vs. avoidance) × Stimuli	-62.69	6.38	< 0.001
Stage of change for exercise[3]	-8.90	26.40	0.780
Stage of change for exercise × Action	-10.16	11.62	0.390
Stage of change for exercise × Stimuli	-8.90	6.38	0.384
Stage of change for exercise × Action× Stimuli	-54.79	12.76	< 0.001
Random Effects		σ^2	
Participants			
Intercept		4971.9	
Action		681.9	
Stimuli (physical activity, sedentary behaviors)		437.5	
Correlation (Intercept, Action)		-0.01	
Correlation (Intercept, Stimuli)		-0.1	
Correlation (Action, Stimuli)		-0.26	
Stimuli (i.e., each pictures)			
Intercept		80.2	
Residual		31613.0	

Table 1. Results of the linear mixed models predicting the relative reaction time required to approach and avoid stimuli depicting physical activity and sedentary behaviors as a function of the stage of change for exercise. The relative reaction time to approach (avoid) stimuli associated to physical activity and sedentary behaviors compared to neutral stimuli was obtained by subtracting each participants' average median reaction times to approach (avoid) neutral stimuli from each specific reaction time to approach (avoid) stimuli depicting physical activity and sedentary; [1] -0.5 = approach; 0.5 = avoidance; [2] -0.5 = physical activity; 0.5 = sedentary behaviors; [3] -0.5 = physically inactive individuals (*preparation stage*); 0.5 = physically active individuals (*maintenance stage*); SE = standard error.

Physically active participants approached physical activity faster than sedentary behaviors (b = 46.83, p < 0.001) and avoided sedentary behaviors faster than physical activity (b = -43.10, p < 0.001). Additionally, physically active participants were faster at approaching compared to avoiding physical activity (b = 39.75, p < 0.001), whereas they were faster at avoiding compared to approaching sedentary behaviors (b = -50.18, p < 0.001).
Physically inactive participants approached physical activity faster than sedentary behaviors (b = 28.49, p = 0.009). Their reaction times were not significantly different when avoiding physical activity and sedentary behaviors (p = 0.502). Additionally, physically inactive participants were faster at approaching compared to avoiding physical activity (b = 22.67, p = 0.021). Their reaction times were not significantly different when avoiding and approaching sedentary behaviors (p = 0.186).

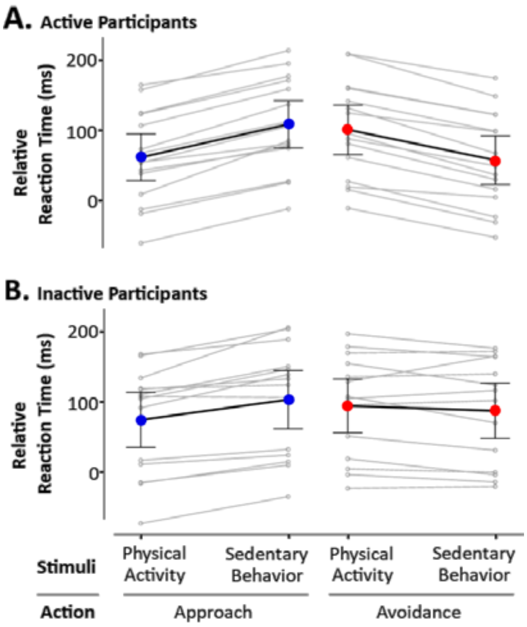

Figure 4. Predicted relative reaction time from the linear mixed model to approach (blue dot) and avoid (red dot) physical activity and sedentary behaviors in physically active (A) and inactive participants (B). Grey points represent individuals' mean of the repeated trials for each conditions (Action and Stimuli). Black points represent overall mean for each conditions. Errors bars represent range going from -1.96SD to +1.96SD for each conditions.

Lateralized Readiness Potentials

S-LRP Onset Latency

Results of the S-LRP onset latency did not show significant main effects of action (p_c = 0.96) and stage of change for exercise (p_c = 0.95). However, results showed a significant main effect of stimuli ($F(1, 27) = 5524.72$, $p < 0.001$, partial η2 = 0.99, $F_c(1, 27) = 7.04$,) as well as a significant interaction between action and stimuli ($F(1, 27) = 9015.19$, $p < 0.001$, partial η2 = 0.97, $F_c(1, 27) = 11.49$; Figure 5). Simple test effects revealed that a longer onset latency to approach stimuli depicting sedentary behaviors (32 ms) compared to stimuli depicting physical activity (-18 ms, $p_c s < 0.001$). Conversely, no significant differences emerged between avoiding physical activity and sedentary behaviors. No significant differences in the onset latency emerged between approaching compared to avoiding sedentary behaviors (p_c = 0.320) or physical activity (p_c = 0.640). All the other effects were nonsignificant.

S–LRP amplitude

The mean S–LRP amplitude was measured within the 385–580 ms range, where the overall S–LRP was maximal. Results of the mixed-subject design ANOVA showed non-significant main effects of action (p = 0.445), stimuli (p = 0.707), and stage of change for exercise (p = 380). However, results showed a significant interaction between action and stimuli ($F(1, 27) = 4.83$, $p = 0.037$, partial η2 = 0.15; Figure 5). Simple test effects revealed that the avoidance of stimuli depicting physical activity (-0.36 μV, SE = 0.16) elicited a larger negative deflection than the avoidance of stimuli depicting sedentary behaviors (0.036 μV, SE = 0.18), $t(28) = -2.34$, $p <$ 0.026 and the approach of physical activity (0.13 μV, SE = 0.21), $t(28) = -2.10$, $p < 0.04$. The other simple effects were not significant ($ps > 0.127$). Results also revealed a significant interaction between stimuli and the stage of change for exercise ($F(1,27) = 11.192$, $p = 0.002$, partial η2 = 0.096). Simple test effects revealed that for physically active individuals, sedentary behaviors (0.181 μV) elicited a larger positive deflection compared to physical activity (-0.120 μV; $t(14) = 2.63$, $p = 0.020$), while marginal differences only emerged among physical inactive individuals (-0.34 vs. -0.09 μV, $p = 0.054$). All the other effects were nonsignificant.

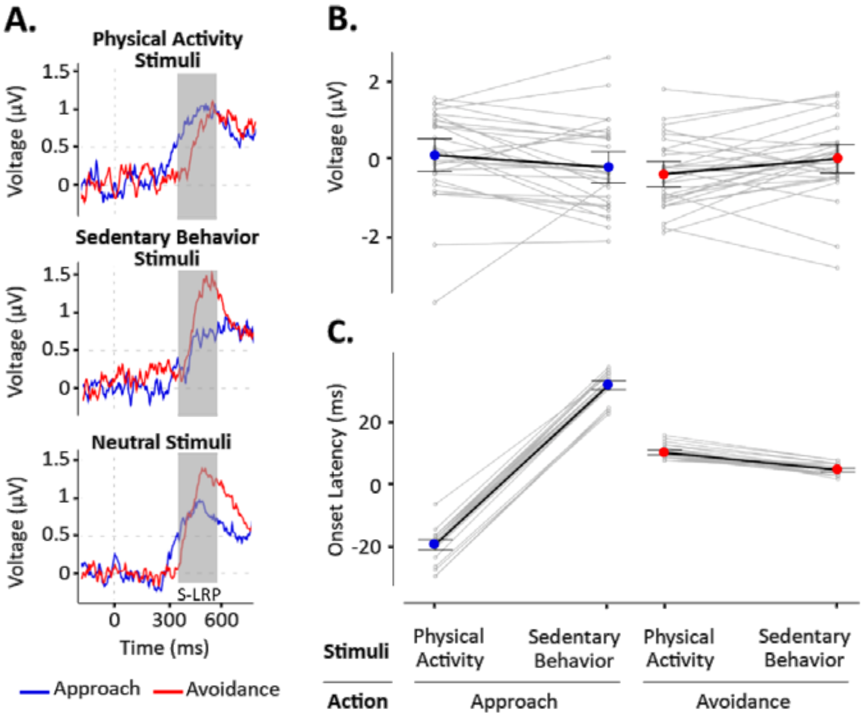

Figure 5. S-LRP results. A. Lateralized Readiness Potential (LRP) signal in the 200–800 ms range when approaching (blue line) and avoiding (red line) stimuli depicting physical activity, sedentary behaviors, and neutral stimuli. The grey area represents the range of time associated with the Stimulus-locked LRP (S-LRP). **B.** S-LRP amplitudes when approaching (blue dot) and avoiding (red dot) stimuli depicting physical activity and sedentary behaviors. The amplitudes reported here represents amplitudes associated with contextual stimuli (i.e., depicting physical activity or sedentary behaviors) relative to the amplitudes associated with neutral stimuli. Accordingly, a positive amplitude represents a larger positive deflection associated with the contextual stimuli compared to the neutral stimuli. **C.** S-LRP onset latencies when approaching (blue dot) and avoiding (red dot) stimuli depicting physical activity and sedentary behaviors. The onset latencies reported here were relative to the onset latencies associated with neutral stimuli. A negative onset latency represents a shorter onset latency in the contextual than neutral stimuli. S-LRP = stimulus-locked Lateralized Readiness Potential. It should be noted the jackknife procedure requires to apply the Greenhouse-Geisser epsilon correction to adjust the degrees of freedom of the F-ratio. It should also be noted that the S-LRP amplitudes showed three individuals that may appear as extremes. However, the potential extreme values were going in the opposite direction as the observed effect. Therefore, the effect was significant despite these individuals, and not because of them.

R–LRP

The grand average waveforms of R–LRP are shown in Figure 5. The mean amplitude of R–LRP was measured within the −352 to −60 ms range where its overall amplitude was maximal for the following negative deflection. Results of the mixed-subject design ANOVA did not show significant main effects of action (p = 0.90), stimuli (p = 0.22), and stage of change for exercise (p = 0.63). The two and three-way interactions were also not significant (ps > 0.25). In line with the results of the R–LRP amplitudes, results of the mixed-subject design ANOVA testing the R–LRP onset latency showed non-significant main effects of action (p_c = 0.45), stimuli (p_c = 0.71), and stage of change for exercise (p_c = 0.90). The two and three-way interactions were also not significant ($p_c s$ > 0.58).

Event-Related Potentials

Cluster-mass analysis

Results of the cluster-mass analysis showed a significant main effect of stimuli at several time-points in the 100–630 ms range (p = 0.0002) with a more negative amplitude for stimuli depicting sedentary behaviors compared to stimuli depicting physical activity. This effect was particularly pronounced and spread between 150 and 350 ms (Figure 6A). The main effect of action was not significant. Results also showed a significant two-way interaction between action and stimuli at several time points between 100 and 400 ms in an area including frontal, central and parietal sites (p = 0.0186; Figure 6C). This interaction effect was particularly pronounced and spread in the 150–325 ms range. Figure 7 illustrates the topographical map for this range period for each condition. Simple effects tests revealed significant amplitude differences when avoiding sedentary behaviors versus physical activity (p = 0.0002), when approaching sedentary behaviors versus physical activity (two clusters show significant effects with p = 0.0144 and p = 0.0002), and when avoiding versus approaching sedentary behaviors (p = 0.0246). Conversely, results showed no significant differences when avoiding or approaching physical activity (lowest p = 0.0956; Supplemental materials 2 to 5). The three-way interaction between action, stimuli, and stage of change toward physical activity was not significant.

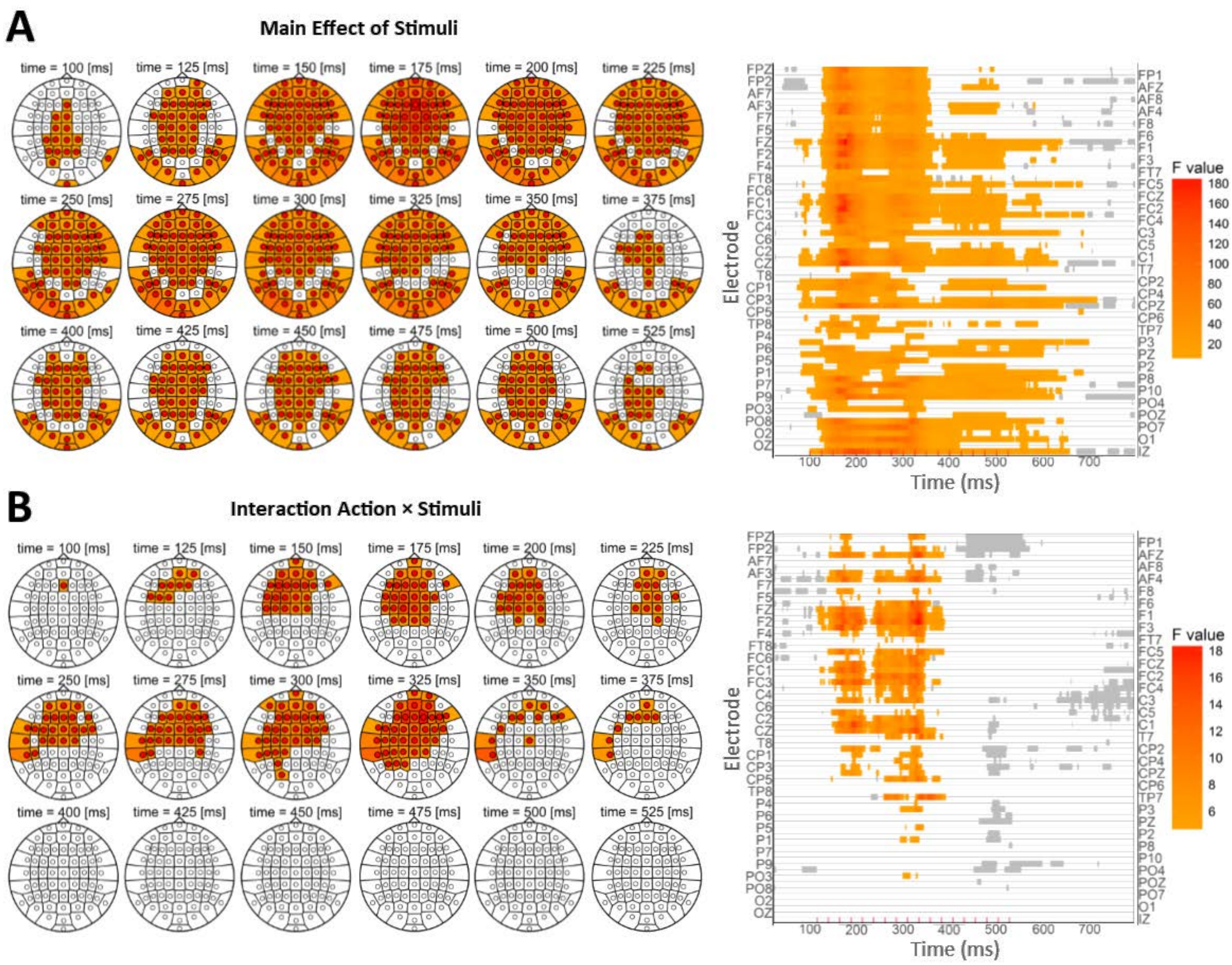

Figure 6. ERP results of the whole-scalp analysis. **A.** Main effect of stimuli for all the electrodes in the 0-800 ms range period. **B.** Two-way interaction between action and stimuli for all the electrodes in the 0-800 ms range period. Results were based on a cluster-mass analysis using non-parametric permutation test and using the family-wise error rate correction.

P1, N1, and N2 ERPs

The first effect, within the 80–130 ms range, was compatible with the P1 ERP and was qualified by a main effect of stimuli with a more positive amplitude for stimuli sedentary behaviors compared to physical activity (Figure 8 illustrates results in P9).

The second effect, within the 100–150 ms range, was compatible with the early N1 ERP and was qualified by a main effect of stimuli with a more negative amplitude for stimuli depicting sedentary behaviors compared to physical activity. Moreover, a two-way interaction between action and stimuli emerged at the end of the period. This interaction was characterized by a more negative amplitude for avoiding sedentary behaviors compared to physical activity. This simple effect also emerged in the approach condition but was less pronounced and emerged at the end of the time period only. Additionally, results revealed a more negative amplitude for avoiding compared to approaching sedentary behaviors and a more negative amplitude for approaching compared to avoiding physical activity. However, these simple effects were not significant (Figure 7 illustrates results from this analysis with the Fcz electrode).

The third effect, within the 150–180 ms range, was compatible with the late N1 ERP and was qualified by a main effect of stimuli, with a more negative EEG amplitude for stimuli depicting sedentary behaviors compared to physical activity (Figure 8 illustrates results in P9).

The fourth effect, within the 230–470 ms range, was compatible with the N2 ERP and was qualified by a main effect of stimuli, with a more negative amplitude for stimuli depicting sedentary behaviors compared to physical activity. Moreover, the N2 ERP was qualified by a two-way interaction between action and stimuli. This interaction was characterized by a more negative amplitude for avoiding sedentary behaviors compared to physical activity. This simple effect also emerged for physical activity, but was less pronounced and was not significant during the whole range period. Additionally, results revealed a more negative amplitude for avoiding compared to approaching sedentary behaviors, but a more negative amplitude for approaching compared to avoiding physical activity. However, only the simple effect of action for sedentary behaviors was significant (Figure 8 illustrates results in Fcz). These P9 and Fcz ERP outcomes were illustrated as they best represented the observed effects in terms of effect sizes. Moreover, they are traditionally used to index the respective ERPs in the literature.

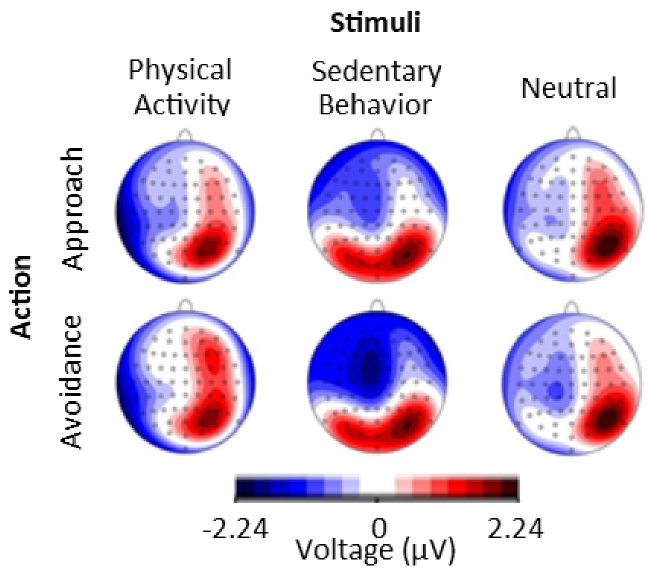

Figure 7. Topographical figures mapping the differences between each condition in the 150–325 ms. The 150–325 ms range was chosen because the interaction between action and stimuli was particularly pronounced and spread within this range. The complete topographical figures for all conditions are presented in the supplemental material 1.

<u>Sensitivity Results</u>

Overall, the behavioral results of the sensitivity analyses were consistent with the main results, except for the simple effects of approaching versus avoiding stimuli depicting physical activity and sedentary behaviors, which were dependent on the type of pictures used as neutral stimuli (i.e., circles or squares; Supplemental material 6). Overall, the ERP results of the sensitivity analyses were consistent with the main results, except for the simple effect of approaching versus avoiding stimuli depicting sedentary behaviors, which did not survive the error rate correction when using either circles or squares as neutral stimuli (Supplemental material 6). Overall, the LRP results of the sensitivity analyses were consistent with the main results. As for the main analysis, the habitual level of physical activity did not modulate the effects on R–LRP amplitudes, S–LRP amplitudes, and onsets (Supplemental material 6).

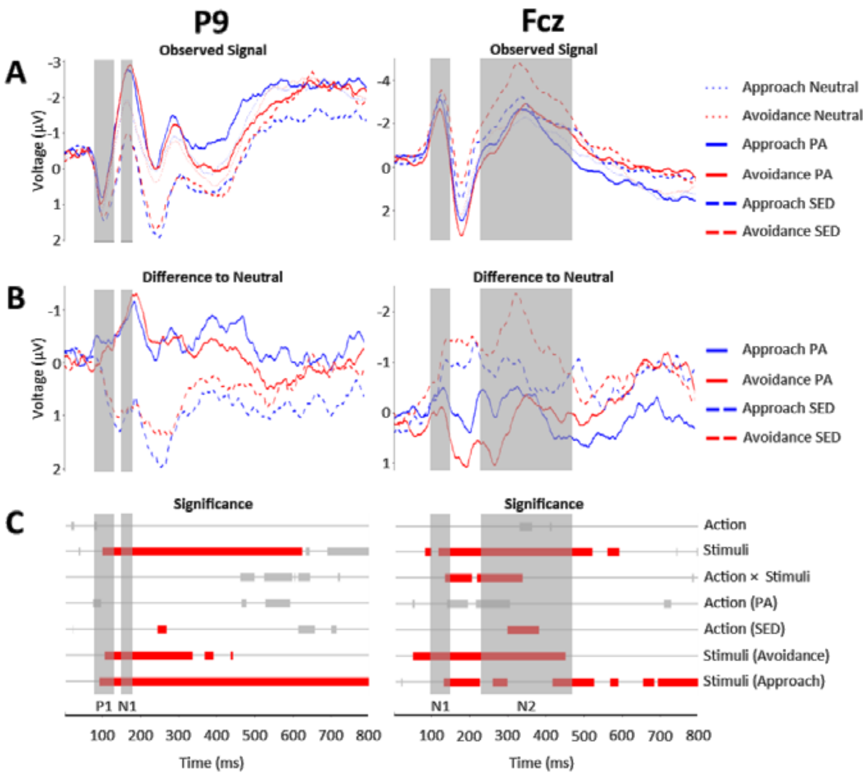

Figure 8. ERP results. A. Observed ERP signal in the 0–800 ms for all the conditions. **B.** Difference in the observed ERP signal for approaching and avoiding stimuli depicting physical activity and sedentary behaviors relative to the observed ERP signal for approaching and avoiding neutral-related stimuli. **C.** Significant effects after the familywise error rate correction. Red bars represent the time range of significant effects. Grey bars represent the time range of effects that did not survive the familywise error correction. For the electrode P9, the first grey are (80–130 ms range) corresponds to the P1 and the second grey area (150–180 ms range) represents the late N1. For the electrode Fcz, the first grey area (100–150 ms range) represents the early N1 ERP results and the second grey area (230–470 ms range) represents the N2.

Discussion

This study revealed that the processes underlying faster reactions to approach physical activity and avoid sedentary behaviors occur during sensory integration (larger positive deflection and earlier S-LRP onset latency), not during motor preparation (no effect on the R-LRP components). Results also showed, for the first time, that avoiding sedentary behaviors triggers higher conflict monitoring (larger early N1), and inhibition (larger N2) than avoiding physical activity, irrespective of the usual physical activity level. These findings suggest that higher levels of control are activated to counteract an innate tendency to approach sedentary behaviors.

Behavioral Outcomes

Approach and Avoidance Tendencies

Results showed that participants were faster at approaching stimuli depicting physical activity compared to sedentary behaviors, whereas they were faster at avoiding stimuli depicting sedentary behaviors compared to physical activity (Hypothesis 1a). Moreover, results showed that these behavioral outcomes were influenced by the level of physical activity (Hypothesis 1b). Specifically, physically active participants were faster at approaching physical activity compared to sedentary behaviors and at avoiding sedentary behaviors compared to physical activity. In contrast, while physically inactive participants were faster at approaching physical activity compared to sedentary behaviors, they were not significantly faster at avoiding sedentary behaviors compared to physical activity. These findings suggest that individuals fail to implement their intention to be physically active because they do not manage to avoid sedentary behaviors.

Approach bias

Additionally, previous behavioral studies showed that young and middle-aged adults, especially those that are physically active, exhibited a positive approach bias toward stimuli depicting physical activity (i.e., they were faster at approaching compared to avoiding physical activity stimuli), but a negative approach bias toward sedentary behaviors (i.e., they were faster at avoiding compared to approaching sedentary behaviors) (Cheval et al., 2014; Cheval et al., 2015; Cheval et al., 2016). However, these previous experiments did not control for the tendency to approach or avoid neutral stimuli. Yet, some individuals may have a tendency to approach rather than avoid neutral stimuli (i.e., a general approach bias), whereas others may have a tendency to avoid rather than approach neutral stimuli (i.e., a general avoidance bias). As such, this absence of control for neutral stimuli may have biased the results. For the first time, our study examined the approach and avoidance tendencies toward stimuli depicting physical activity and sedentary behaviors relative to neutral stimuli. Results showed faster approach than avoidance of physical activity and the opposite for sedentary behaviors. These effects were more pronounced in physically active compared to inactive individuals. These findings suggest that individuals who successfully implemented their intention to be physically active have developed positive affective association with physical activity (Williams et al., 2008; Brand and Ekkekakis, 2017) and/or efficient strategies to increase their automatic tendencies to approach physical activity and decrease those to avoid sedentary behaviors.

Cortical Outcomes

The behavioral results reported in the previous section are inconsistent with the fact that most people fail to exercise regularly despite the intention to be physically active (Rhodes and Dickau, 2012; Rhodes and Bruijn, 2013). Therefore, investigating the neural mechanisms underlying these reaction-time differences was necessary to understand this discrepancy. This study examined for the first time the cortical activity underlying automatic approach and avoidance tendencies toward physical activity and sedentary behaviors.

Lateralized Readiness Potentials

LRP results showed a shorter latency of S-LRP when approaching stimuli depicting physical activity compared to sedentary behaviors, a larger positive deflection of S-LRP when avoiding stimuli depicting sedentary behaviors compared to physical activity, and a smaller positive deflection when avoiding compared to approaching stimuli depicting physical activity. These findings are consistent with the behavioral results, and showed, for the first time, that the mechanisms underlying the faster reaction times to approach physical activity and to avoid sedentary behaviors take place during sensory integration (S-LRP), not during motor planning

(R-LRP) (Hypothesis 2). These results also highlight that approaching physical activity and avoiding sedentary behaviors represent congruent conditions (i.e., the intended response supports the required response), whereas avoiding physical activity and approaching sedentary behaviors represent incongruent conditions (i.e., the intended response hampers the required response). These observations are consistent with the fact that all the participants of this study intended to be physically active and, as such, that avoiding physical activity and approaching sedentary behaviors was conflicting with their conscious goal of becoming physically active. Additionally, in physically active individuals, LRP results revealed that sedentary behaviors were associated with higher positive deflection compared to physical activity, irrespective of whether these stimuli should be approached or avoided. This finding suggests that sensory integration is more efficient in individuals who manage to reach their physical activity goals, allowing earlier reactions to potential threat for their conscious goal of physical activity. In contrast, individuals who did not reach their physical activity goals seemed to not have not developed these faster/more efficient sensory integration processes.

Event-Related Potentials

ERP results revealed higher levels of conflict monitoring (larger early N1), and inhibition (larger N2) when avoiding stimuli depicting sedentary behaviors compared to physical activity (Hypothesis 3). These results suggest that higher levels of control were activated to counteract an innate tendency to approach sedentary behaviors. This finding is consistent with the proposition presented in a recent systematic review contending that behaviors minimizing energetic cost are rewarding and, as such, are automatically sought (Cheval et al., 2018). This proposition concurs with previous work claiming that people possess an innate tendency to conserve energy and avoid unnecessary physical exertion (Lieberman, 2015; Lee et al., 2016), thereby explaining the negative affect that could be experienced during vigorous exercise (Ekkekakis et al., 2011; Brand and Ekkekakis, 2017; Ekkekakis, 2017) and the general evaluation of physical effort as a cost (Croxson et al., 2009; Shadmehr et al., 2016). However, these cortical outcomes were not significantly influenced by the habitual level of physical activity (Hypothesis 4). Taken together, these findings call for a cautious interpretation of the behavioral results. Faster reaction times when approaching physical activity and avoiding sedentary do not imply an innate tendency to approach physical activity, i.e., movement and energy expenditure, as often interpreted in the literature. Our results showed that these behavioral observations are actually associated with higher levels of inhibition likely aiming at counteracting an innate tendency to avoid physical exertion and allowing individuals to be more physically active.

ERP results also revealed higher levels of attentional processing (larger P1 and late N1), conflict monitoring (larger early N1), and inhibition (larger N2) when exposed to sedentary behaviors compared to physical activity stimuli, irrespective of whether these stimuli should be approached or avoided. These results are consistent with previous studies arguing that stimuli related to sedentary behaviors can represent a threatening temptation for individuals who intend to be or are physically active (as the participants of our study) as these stimuli interfere with the successful implementation of physical activity goals (Rouse et al., 2013; Cheval et al., 2017). As such, stimuli associated with sedentary behaviors may automatically trigger higher-level mechanisms preparing the individual to overcome this potential threat.

Strengths and Limitations

Strengths of our study include 1) the investigation, for the first time, of the cortical activity underlying automatic approach tendencies toward physical activity and sedentary behaviors, 2) the use of different ERP metrics that consistently showed that avoiding sedentary behaviors requires more cortical resources than avoiding physical activity, 3) the use of LRP measures to investigate the processes occurring during sensory integration and motor preparation, 4) the use of sophisticated EEG statistical analyses suited to examine the whole scalp throughout the duration of the response, 5) the control of approach and avoidance tendencies toward neutral stimuli, and 6) the validation of these results through sensitivity analyses. However, some potential limitations should also be noted. First, the usual level of physical activity was assessed using a self-reported questionnaire, which may not accurately reflect the objective level of physical activity. Yet, two independent and validated scales were used to assess physical activity and yielded consistent results. Second, the sample size of this study was small. However, the linear mixed models used to analyze the behavioral data allowed the inclusion of all trials in the model (i.e., not the average performance per individual), which yielded an appropriate statistical power. By contrast, there was a potential power issue in the EEG analysis. In view of these two limitations (self-reported assessment of physical activity and low sample size), the non-significant effect of the level of physical activity on the cortical activity underlying the automatic approach and avoidance tendencies toward physical activity and sedentary behaviors should be interpreted with caution. Third, this study involved individuals who were physically active or who intended to. Future research should examine whether the neural processes underlying approach and avoidance tendencies differ between physically inactive individuals who intend and do not intend to be physically active. In the absence of intention to be active (i.e., to approach physical activity and avoid sedentary behaviors), sedentary behaviors may not be perceived as a threat. Therefore, sedentary behaviors may not affect conflict monitoring, inhibition, and motor preparation. Fourth, the neutral stimuli (i.e., square vs. circles) changed the simple effects of approaching compared to avoiding stimuli depicting physical activity and sedentary behaviors. Accordingly, interpreting these simple effects seems inappropriate. Future studies seeking to control for the automatic approach-avoidance bias toward neutral stimuli should carefully pre-test the neutral stimuli.

Conclusion

To sum up, our findings revealed that faster reaction times to approach physical activity and avoid sedentary behaviors that are related to processes occurring during sensory integration, not motor preparation. However, results showed that faster reaction times when avoiding stimuli depicting sedentary behaviors require higher levels of conflict monitoring and inhibition compared to stimuli depicting physical activity. Contrary to what behavioral results suggested, these neural findings showed that sedentary behaviors are innately attractive and that individuals intending to be active need to activate cortical resources to counteract this innate attraction.

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SUPPLEMENTARY MATERIALS

Supplementary material 1. Topographical figures for all conditions.

Supplementary material 2. Results of the results for the simple effect of approaching stimuli depicting sedentary behaviors rather than physical activity.

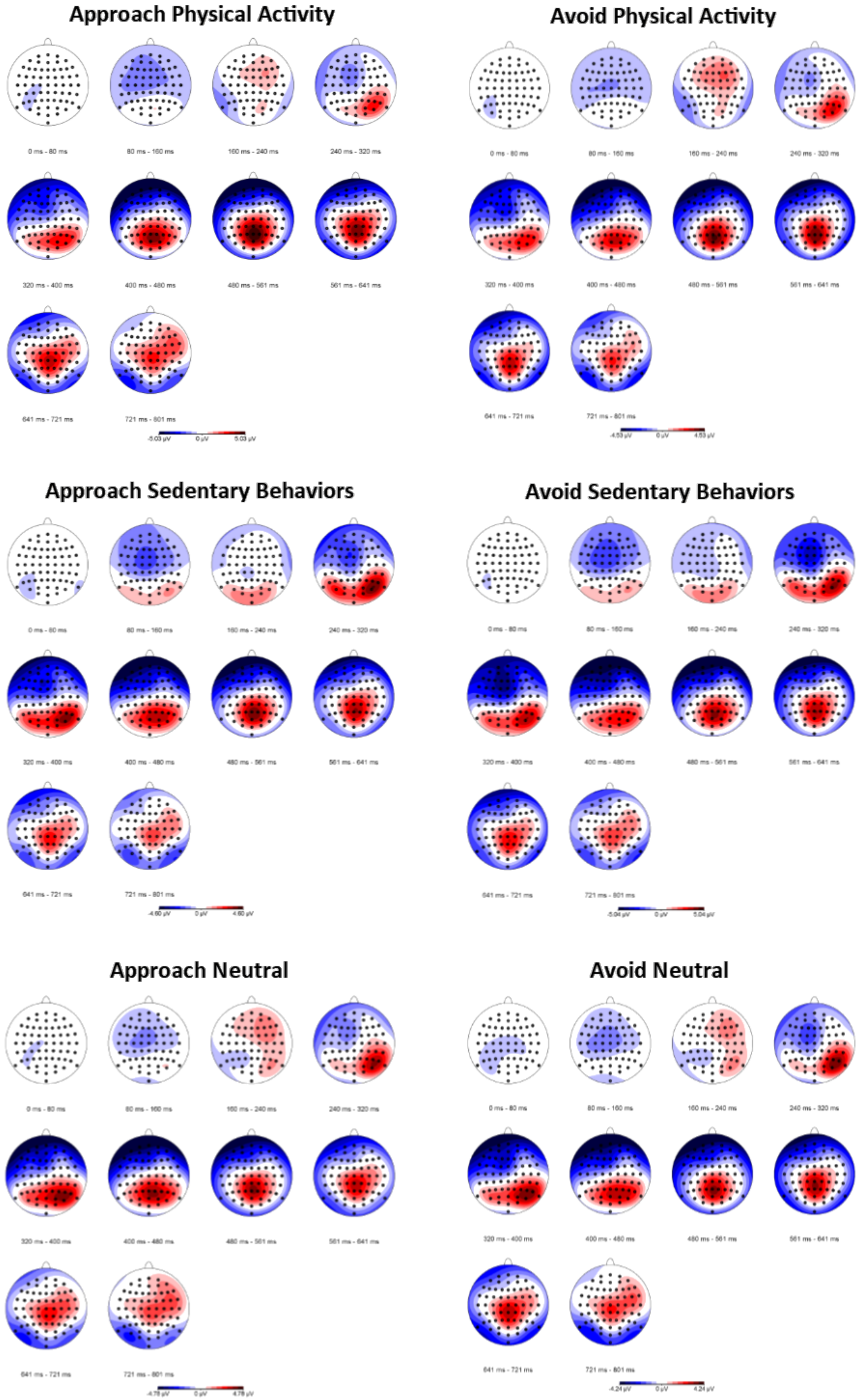
Supplementary material 3. Results of the results for the simple effect of avoiding stimuli depicting sedentary behaviors rather than physical activity.

Supplementary material 4. Results of the results for the simple effect of approaching rather than avoiding stimuli depicting sedentary behaviors.

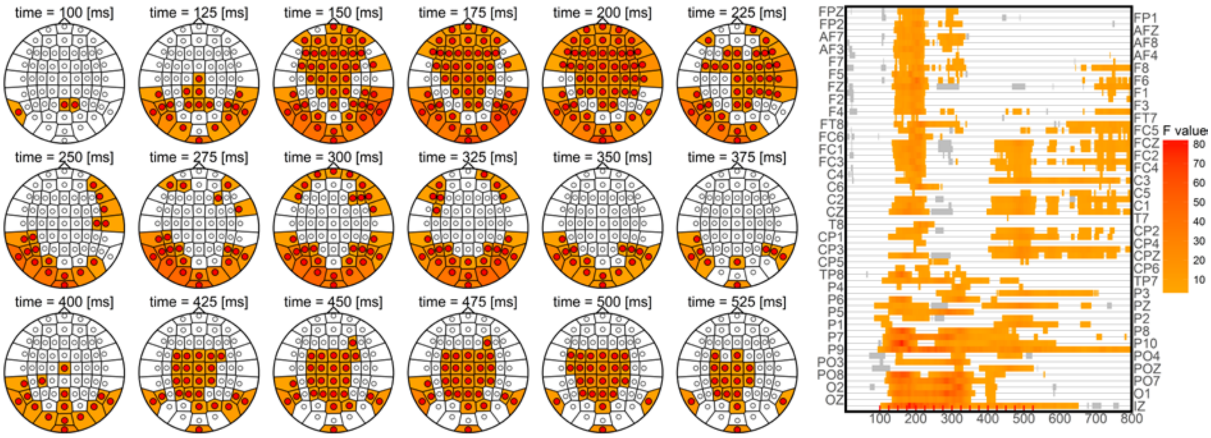
Supplementary material 5. Results of the results for the simple effect of approaching rather than avoiding stimuli depicting physical activity.

Supplementary material 6. Summary of the sensitivity and complementary analyses.

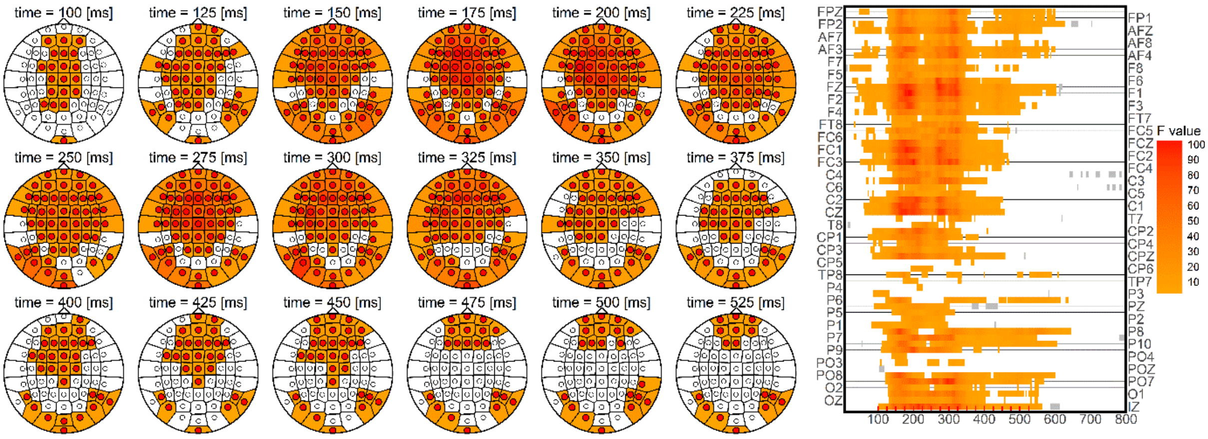
Supplementary material 1. Topographical figures for all conditions.



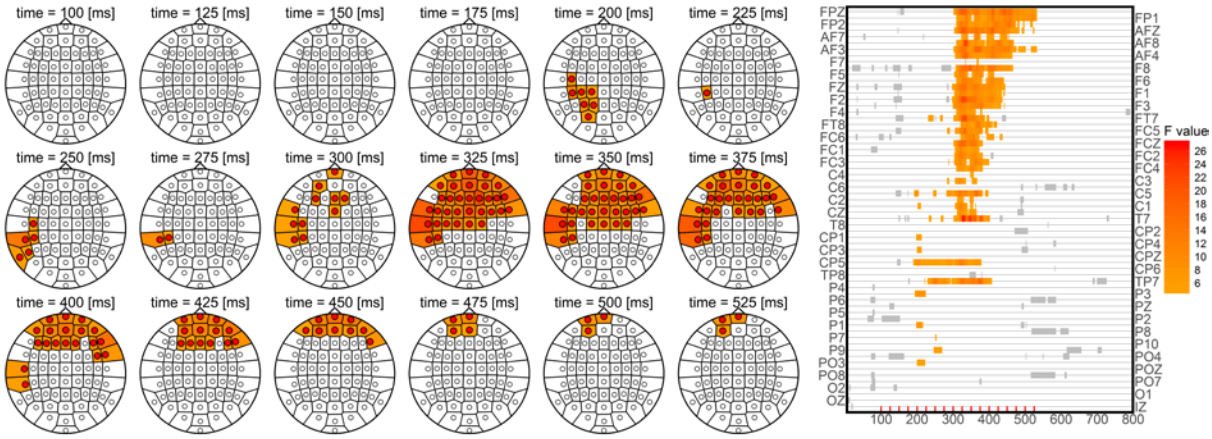
Supplementary material 2. Results of the results for the simple effect of approaching stimuli depicting sedentary behaviors rather than physical activity.



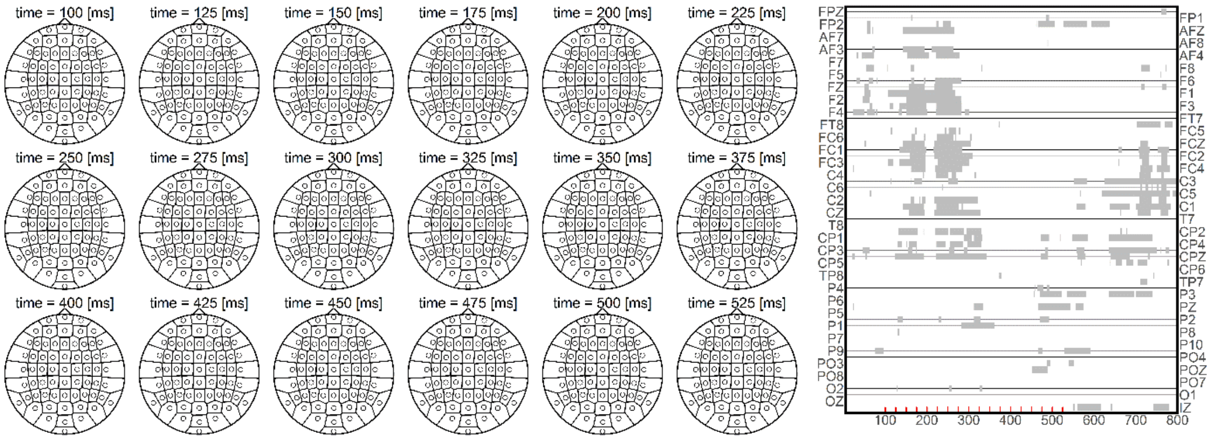
Supplementary material 3. Results of the results for the simple effect of avoiding stimuli depicting sedentary behaviors rather than physical activity.



Supplementary material 4. Results of the results for the simple effect of approaching rather than avoiding stimuli depicting sedentary behaviors.



Supplementary material 5. Results of the results for the simple effect of approaching rather than avoiding stimuli depicting physical activity.



Supplemental materials 6. Summary of the sensitivity analyses.

	Description	Main results
1	Using circles as neutral pictures	**Behavioral results:** The simple effect of approaching rather than avoiding stimuli depicting physical activity became non-significant. **ERP results:** The simple effect of approaching rather than avoiding stimuli depicting sedentary behaviors became non-significant. **LRP results:** Results were essentially similar to those of the main analysis.
2	Using squares as neutral pictures	**Behavioral results:** The simple effect of approaching rather than avoiding stimuli depicting sedentary behaviors became non-significant. **ERP results:** The simple effect of approaching rather than avoiding stimuli depicting sedentary behaviors became non-significant. **LRP results:** Results were essentially similar to those of the main analysis.
3	Using the international physical activity questionnaire	**Behavioral results:** Results were essentially similar to those of the main analysis. **ERP results:** Results were essentially similar to those of the main analysis. **LRP results:** Results were essentially similar to those of the main analysis.