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Frequent physical exercise is associated with better ability to regulate negative emotions in adult women: The electrophysiological evidence

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ABSTRACT

The study aimed to investigate the relationship between the frequency of physical exercise and the ability to control negative emotions in adult women. On the basis of the pre-screening, 26 frequently active and 26 infrequently active young adult women (mean age = 22.9, and 23, respectively) were invited to participate in the study. We assessed their ability to control negative emotions using behavioral and electrophysiological measures during an emotion regulation task. To control negative emotions, participants were trained in reappraisal, a cognitive strategy which involves reinterpretation of emotional stimuli (here negative emotional pictures). Although no significant effects were observed in behavioral measures, the late positive potential (LPP, an electrophysiological marker of emotional response) showed that more frequently active group displayed better efficacy of negative emotion regulation (i.e., greater difference in response to reinterpreted vs passively watched negative pictures). This effect was further confirmed by a positive relationship between the frequency of physical exercise and the LPP index of reappraisal efficacy: the more frequently active the participants were, the larger the reappraisal efficacy they demonstrated. Overall, the study suggests that frequent physical exercise may lead to better efficacy of controlling negative emotions in women.

1. Introduction

Negative emotions, though unpleasant in the moment, usually signal alarming processes in our body and trigger adaptive behaviors (Parrott, 1993). However, sometimes negative emotions are not well matched to the current situation. When negative emotions are not relevant to the current situation, they can lead to unwelcome mental states such as loss of control, depression or panic (Dziemidok, Makara-Studzińska, & Jarosz, 2011; Espeset, Gulliksen, Nordbø, Skårderud, & Holte, 2012; Sirois & Burg, 2003). In such situations, the ability to control negative emotions (so-called emotion regulation) might play a key role in ensuring well-being. Emotion regulation (ER) is usually defined as a set of cognitive processes responsible for monitoring, evaluating and modifying emotional reactions (Gross, 1998; Thompson, 1994). Since efficient ER provides a balanced emotional state on a daily basis and thereby helps us undertake our everyday activities, investigation of factors that improve efficacy of ER is highly desirable. In recent years, a growing body of evidence has shown that regular physical exercise might be related to better cognitive and emotional functioning (Guiney & Machado, 2013; Richards et al., 2015). However, still little is known about whether frequent physical exercise could also be related to more effective ability to regulate negative emotions.

1.1. Reappraisal as a strategy of emotion regulation

People regulate their negative emotions using different strategies, among which reappraisal (also called cognitive reinterpretation; Gross & John, 2003) is considered as the most effective strategy. Reappraisal relies on reinterpretation of an emotion-eliciting situation in a way that down-regulates (i.e. decreases) the intensity of its emotional impact by altering its meaning. For example, when people are viewing an unpleasant scene of a car accident, they can downregulate the intensity of the emotional reaction (i.e. decrease its emotional impact) by imagining an optimistic outcome of this situation (e.g. “All accident victims will recover fully soon”) or by denying its reality (e.g. “It's just a film scene”) (Gross & John, 2003; Ochsner & Gross, 2005). Recent evidence shows that the efficacy of reappraisal depends on an individual's level of anxiety (e.g. Cisler, Olatunji, Feldner, & Forsyth, 2010; Mennin,

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Heimberg, Turk, & Fresco, 2005). Since anxious individuals are characterized by both increased emotional reactivity and lowered ability to control negative emotions, their level of anxiety substantially affects their efficiency of ER. At the same time, individuals have different personal tendencies to regulate their emotions on daily basis: they might prefer to use reappraisal or regulate their emotions using other strategies (e.g. suppress their negative emotions) (Gross & John, 2003). In turn, personal tendencies also affects the overall efficacy of ER.

In experimental settings, reappraisal as an ER strategy is usually investigated using a picture presentation paradigm (Hajcak & Nieuwenhuis, 2006; Moser, Hartwig, Moran, Jendrusina, & Kross, 2014; Wyczesany & Ligeza, 2017). Participants are presented with negative pictures and asked either to passively view them (the control condition) or to reappraise them (i.e. to reinterpret their meaning in order to decrease their negative impact; the experimental condition). Afterwards, participants rate the perceived unpleasantness evoked by the picture. Compared to the control condition, participants who reappraise the pictures (the experimental condition) should report less intense negative feelings (Hajcak & Nieuwenhuis, 2006; McRae, 2016; Ochsner, Bunge, Gross, & Gabrieli, 2002). The difference in intensity of negative feelings across the reappraisal and the control condition is assumed to reflect the effect of reappraisal or reappraisal efficacy (i.e., the greater the difference in the rating between the reappraisal and the control condition, the greater the reappraisal efficacy). It is worth to mention, however, that self-reports come with some inherent shortcomings. Participants may be more or less optimistic in their assessment, or they may try to adjust to the expectations of the experiment.

A reappraisal efficacy (i.e., lower emotional response after efficient reappraisal) has been further explored by studies employing the event-related potential (ERP) measurement. ERPs provide insight into the cerebral basis of cognitive processes and assure excellent temporal measurement precision; therefore, they gave the opportunity not only to observe the end-point of neural processing (i.e. self-reported feelings of participants) but also to track online the cognitive processes leading to the behaviorally observable outcomes (Hajcak & Nieuwenhuis, 2006). Most ERP studies on the reappraisal efficacy have focused on the Late Positive Potential (LPP) component (for an integrative review, see Hajcak, MacNamara, & Olvet, 2010).

The LPP is a well-established neural index of emotional perception and emotional reactivity in humans which reflects enhanced processing of emotional stimuli. It is a slow positive deflection that starts approximately 300–500 ms post-stimuli, and is sustained throughout the duration of stimuli presentation (most often emotional pictures) (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000). The LPP demonstrates the posterior topography (which accumulates around Pz electrode). The LPP is considered as a long-lasting ERP component and thus it can be quantified in some consecutive time windows. For example, while presenting participant with an emotional picture lasting for 5000 ms, the component would be observed in a time window ranging from around 400 up to 5000 ms. Given the relatively wide time window of this component, a standard in the LPP literature is to divide this component into several shorter, consecutive time windows (e.g. 400–1000 ms; 1000–2000 ms; 2000–3000 ms etc.) and analyze each of them separately. This allows to monitor the temporal dynamics of the ongoing emotional process, by observing changes in emotional response in time (e.g. Krompinger, Moser, & Simons, 2008; Moran, Jendrusina, & Moser, 2013; Schönfelder, Kanske, Heissler, & Wessa, 2014; Wyczesany & Ligeza, 2017;Thiruchselvam et al., 2011).

Despite years of research on the LPP, the brain structures that are responsible for generating this ERP component are not well established. Recent studies (e.g. Liu, Huang, McGinnis, Keil, & Ding, 2012), by recording EEG and fMRI simultaneously, suggest that the LPP is generated and modulated by an extensive brain network comprised of both cortical and subcortical structures. These structures are related to visual, control, and emotional processing and their contribution to the LPP is valence-specific. For positive pictures, the LPP amplitude is mostly related to activity of occipitotemporal junction, medial prefrontal cortex, amygdala, and precuneus, whereas for negative pictures, the LPP is mostly related to activity in ventrolateral prefrontal cortex, insula, and posterior cingulate cortex.

The LPP investigated in the picture presentation paradigm is more pronounced (i.e. more positive) for positive and negative picture, relative to neutral stimuli, and such an effect is usually interpreted as evidence for greater emotional response in a condition eliciting emotions (Olofsson, Nordin, Sequeira, & Polich, 2008; Schupp et al., 2000).

In the previous studies that investigated the reappraisal using the LPP (for a review see: Hajcak et al., 2010), less positive amplitude of the LPP is usually reported in the reappraisal condition (i.e. reappraise a negative picture) as compared to the control one (i.e. watch a negative picture). A less positive LPP in the reappraisal condition is assumed to reflect decreased emotional response and, in turn, has been interpreted as evidence for efficacy of this emotion regulation strategy (Moran et al., 2013). Despite the many advantages of the LPP measurement in investigating the reappraisal efficacy, to the best of our knowledge, this measure has never before been used to study the relationship between physical exercise and the ability to control negative emotions.

1.2. Evidence for relationship between physical exercise and efficiency of reappraisal

An impact of the physical exercise on our cognitive functioning has been gaining more and more research agenda. Many studies have shown positive influences of the physical exercise on cognitive processes including inhibition, attention, and conflict resolution (for a review see: Ludyga, Gerber, Brand, Holsboer-Trachsler, & Pühse, 2016). Furthermore, the physical exercise has been shown to support the brain systems related to the cognitive processes. Specifically, the physical exercise has been shown to increase gray matter volume in frontal and hippocampal regions, reduce damages in the gray matter and facilitate releases of neurotrophic factors such as BDNF (Colcombe et al., 2006; Erickson et al., 2011; Hötting, Schickert, Kaiser, Röder, & Schmidt-Kassow, 2016).

Given a number of studies showing benefitting role of the physical exercise for the general cognitive processes, it might well be that the physical exercise also positively affects the cognitive processes that govern the emotional functioning. Interestingly, theoretical models of the reappraisal imply that the cognitive processes are actively involved in the reappraisal as they adjust attention and memory capacities in order to ensure the successful reappraisal (Ochsner & Gross, 2005). It might well be therefore that the physical exercise impacts not only general cognitive processes but also more specific ones such as the efficacy of reappraisal. If this is the case, such a finding would be another important argument in the ongoing debate on the role of physical exercise in improving humans' quality of daily life (Penedo & Dahn, 2005).

A recent study by Bernstein and McNally (2017) provided some evidence for the positive impact of an aerobic exercise session on the process of generating emotion control strategies. In this study, the participants were randomly assigned to group either stretching or jogging for 30 min. Then, they underwent negative and positive mood induction (using film clips) followed by a measurement of their emotional response and emotional regulation tendencies (i.e. Difficulties in Emotion Regulation Scale, Coping Self-Efficacy Scale). The study showed that the participants with negative mood induced perceived more difficulty, when generating regulatory strategies (i.e., higher scores in Difficulties in Emotion Regulation Scale) (as compared to the participants with positive mood induced). At the same time, however, an aerobic exercise (as compared to stretching) substantially reduced this difficulty, showing that this type of exercise might benefit generation processes related to emotion regulation. This study shed some light on the role of physical exercise in regulating emotions. Nevertheless, still little is known about the relationship between the physical exercise and the efficacy of specific emotion control strategies. So far, we can find only one study that has investigated the relationship between the frequency of physical exercise and the efficacy of reappraisal (i.e. Giles et al., 2017).

In their study, Giles et al. examined whether the level of physical activity (as assessed by a self-reported questionnaire) is related to the efficacy of reappraisal. The authors used the picture presentation paradigm in which participants are instructed either to passively attend or to reappraise negative pictures (the control condition and the reappraisal condition, respectively). In the study, a behavioral measure (i.e. self-reporting of negative feelings in response to negative pictures in control vs. experimental condition) was accompanied by measuring brain oxygenation using functional near-infrared spectroscopy (fNIRS). When using fNIRS, greater oxygenation of cortex should indicate greater engagement of a brain mechanism underlying cognitive performance; this allowed the authors to explore changes in oxygenation of the PFC related to the efficacy of reappraisal.

In the behavioral data, Giles et al. observed the classic effect of reappraisal: reduced negative feeling in the reappraisal condition as compared to the control condition. The authors further showed that the reappraisal effect positively correlated with the level of physical activity in their behavioral measure: the more physically active the participants were, the greater the difference in the perceived unpleasantness between the two conditions they demonstrated. Such a finding indicates better efficacy of the reappraisal strategy when participants are more physically active. In the fNIRS data, the authors found no evidence for the reappraisal effect: the PFC oxygenation did not differ across the task conditions (i.e. reappraising vs. passively watching). As such, the fNIRS data seems to challenge the behavioral findings of this study.

It should be noted here, however, that the fNIRS seems not to be an appropriate instrument to measure the effects of reappraisal. There are only two studies so far that used the fNIRS to investigate effects of reappraisal (Giles et al., 2017; Glotzbach et al., 2011) and none of them provided evidence for the reappraisal efficacy in the PFC oxygenation (i.e. no difference in PFC oxygenation between the reappraisal and the control condition observed). Given the poor spatial resolution of fNIRS, it might well be that fNIRS is not able to detect subtle changes of brain activation related to the reappraisal.

Summing up, we can find only very limited and puzzling evidence regarding the relationship between frequency of physical activity and reappraisal. Therefore, to elucidate a relationship between the frequency of physical activity and the reappraisal efficacy, the studies with more refined neural measures (e.g. the LPP ERP component) are needed.

1.3. The aim of the study

The present study attempted to elucidate the relationship between the aerobic, physical activity and the efficacy of controlling negative emotions in adult women. To this aim, we tested participants who practiced the aerobic type of physical exercise but differed in the frequency of exercise. When testing the ability to control negative emotions, we focused on the reappraisal, a cognitive strategy of controlling emotions which required participants to reinterpret the negative pictures in a less negative manner. In the study, participants performed the picture presentation paradigm using the reappraisal strategy when both behavioral and LPP measurements were recorded. We hypothesized that compared with the infrequently active group (less than one session of aerobic exercise a week), the frequently active group (more than three sessions of aerobic exercise a week) would demonstrate greater reappraisal efficacy, as indexed by self-reports and magnitude of the LPP component.

In order to control for variables that might be confounded with the experimental manipulation in the current study, we measured individual differences related to the level of anxiety (The State-Trait Anxiety Inventory, Spielberger, 1983) and the habitual use of ER strategies (Emotion Regulation Questionnaire; Gross & John, 2003). In addition, given little evidence for the role of the physical activity in the ability to control negative emotions, we took an exploratory approach and tested the relationships between the reappraisal efficacy and some additional measures of the physical activity. A questionnaire measuring physical activity levels (as assessed by Seven-Days Physical Activity Recall Questionnaire; SDPARQ) allowed us to quantify individual levels of physical activity for each participant. Finally, a measure of physical work capacity (i.e. as measured in the peak oxygen uptake protocol; so called the VO2peak test) allowed us to verify self-reported measures (by verifying increased physical work capacity in more active participants), and additionally, explore its relationship with the ability to control negative emotions.

2. Methods

2.1. Participants

Participants were recruited via advertisements posted on websites and social media portals of universities in Krakow, Poland. Participants interested in volunteering in the experiment were contacted via email and pre-screened for their physical exercise experience. For the pre-screening, we used an online survey that consisted of questions about (1) type ("What type of physical activity do you do?"), (2) quantity ("How many times per week do you usually do those activities?; "How long does one session usually take?)", and (3) intensity of physical exercise ("What is the intensity of the activity usually practiced by you?").

Based on the survey output, participants that reported moderate to vigorous intensity of aerobic physical activity (intensity when breathing becomes more pronounced and conversation starts to be difficult to maintain, e.g. running, cycling, swimming, cross-training) were selected and assigned to one of the two groups that differed in frequency of aerobic physical activity: frequently active or infrequently active. The frequently active group consisted of participants that declared frequent involvement in aerobic activities (at least three times per week for at least one year). The infrequently active group consisted of participants who declared less frequent (less than one time per week for at least one year) involvement in a similar aerobic exercise of the same intensity. Participants were matched across the groups in terms of exercise discipline: running, cycling and jogging. Of the 140 women who completed the survey, 52 met the criteria and were invited to participate in the experiment (26 participants per each group).[1] Participants' characteristics are provided in Table 1.

2.1.1. Power calculation

An a priori power analysis revealed that 52 participants were needed to detect an effect of repeated measures: within-between subject interaction (effect size, $\eta 2 = 0.062$ was pulled from previous study which also assessed LPP component using similar design, task, and picture database; Wyczesany & Ligeza, 2017). This estimate was calculated using G*Power software and based on a correlation of 0.5 (Cronbach's alpha) between two repeated measures from two groups and an alpha of 0.05 (Faul, Erdfelder, Lang, & Buchner, 2007).

[1] Our decision to test only female participants was dictated by both methodological and pragmatic reasons. In the light of expected difficulties with recruitment of highly homogenous participant sample, we decided to eliminate one factor which could lead to heterogeneity of the compared groups: testing participants of one gender seemed to help to achieve this goal as there are considerable gender differences in reappraising negative emotions (McRae, Ochsner, Mauss, Gabrieli, & Gross, 2008). The decision to focus on female and not male participants only was due to the fact that male participants tend to use automatic emotion regulation rather than reappraisal in the experimental settings.

Table 1
Participants characteristics (M ± SD).

	Infrequently active group	Frequently active group	Total
n	26	26	52
Age (years)	23.00 ± 2.67	22.92 ± 2.48	22.96 ± 2.55
Height (cm)	166.84 ± 6.18	165.50 ± 7.26	166.17 ± 6.71
Weight (kg)	60.92 ± 11.26	59.10 ± 7.49	60.01 ± 9.51
BMI (kg/m^2)	21.90 ± 4.08	21.56 ± 2.15	21.73 ± 3.23
Physical activity (hours:min/month) [a]	3:29 ± 4:53	23:14 ± 9:40	13:22 ± 6:42
Exercise intensity (BORG scale)	14.6 ± 4.2	14.4 ± 4.4	14.4. ± 4.3
SDPARQ (kcal/day)[a]	2229 ± 468	2620 ± 501	2424 ± 519
VO2peak (mL·kg^{-1}·min^{-1})[a]	37.72 ± 8.60	50.10 ± 10.42	43.91 ± 11.34
Anxiety (STAI trait)[a]	46.19 ± 11.21	38.12 ± 8.44	42.15 ± 10.64
Cognitive reappraisal (ERQ)	29.34 ± 6.07	32.42 ± 5.19	30.88 ± 5.80
Expressive suppression (ERQ)	15.00 ± 4.19	13.46 ± 5.73	14.23 ± 5.03

Note. BMI = body mass index; *SDPARQ* = Seven-Days Physical Activity Recall Questionnaire; *VO2peak* = maximal oxygen uptake; *ERQ* = Emotion Regulation Questionnaire.

[a] Significant difference, unpaired Student's *t*-test between infrequently and frequently active group, $p < .05$.

2.2. Experimental task

2.2.1. Pictures

105 pictures were selected from the Nencki Affective Pictures System (NAPS) (Marchewka, Żurawski, Jednoróg, & Grabowska, 2013) of which 35 were neutral (food, landscapes, households, neutral animals, people in daily activities) and 70 were negative (disgusting food, sad people, accidents, violent images, animal mutilations, surgical procedures). Pictures were split into three unique sets: 1 set of 35 neutral pictures (called neutral set) and 2 sets of 35 negative pictures each (first and second negative set). An additional 21 negative and 7 neutral pictures were selected to enable reappraisal training before the experimental session.

The NAPS scale ranged from "1" (for the most negative and the least arousing pictures) to "10" (for the most positive and the most arousing pictures). Normative ratings of the picture sets (pulled from established NAPS standards) were as follows: 1) neutral set – mean valence = 4.99, SD = 1.07, mean arousal = 4.94, SD = 1.13[2]; 2) first negative set – mean valence = 2.39, SD = 1.19, mean arousal = 6.96; SD = 1.41[3]; 3) second negative set – mean valence = 2.39, SD = 1.24, mean arousal = 6.95, SD = 1.44[4]. The neutral and negative sets differed in their normative ratings of valence and arousal (*ps* < 0.01), but the two sets of negative pictures were matched in their normative ratings and did not differ with regard to valence and arousal (*ns*). All of the pictures occupied 1024 × 768 out of 1920 × 1080 pixels of the computer screen and were presented against a black background.

2.2.2. Reappraisal task

The task was presented using PsychoPy v1.82 software (Peirce, 2008) on a computer with a 27″ high definition screen. Each trial began with the presentation of a cue: the word "WATCH" or "CONTROL" for 3000 ms. The word "WATCH" was displayed in blue and the word "CONTROL" was displayed in yellow in order to make task performance easier. After presentation of the cue, the fixation cross was presented for a random duration (400–800 ms), followed by 1000 ms of a blank screen. Afterwards, a picture was presented for 5000 ms. Depending on the cue, participants were asked either to passively watch the picture in order to experience it naturally ("WATCH" cue) or to reinterpret the meaning of the picture in order to decrease its negative impact ("CONTROL" cue).

After the presentation of a picture, the participant rated the perceived unpleasantness evoked by it. The responses were given using on a bipolar visual analog scale (VAS), ranging from "neutral" (left hand end of the line) to "very negative" (right hand end of the line). Participants were asked to move the pointer from the left hand end of the scale towards the right hand end of the scale until the pointer's position on the scale represented an appropriate negativity of their feelings evoked by the picture. For the purposes of the statistical analysis, a distance between the left hand end and the pointer's position was then decoded to numerical values ranging from 0 ("neutral feeling", the left hand end of the line) to 100 ("very negative feeling", the right hand end of the line).

Pictures for the watch neutral condition were randomly assigned from the neutral set of pictures. The pictures for the watch negative and control negative conditions were randomly assigned either from *the first* or the *second negative set.* Assignment of a particular set of negative pictures (first, second) to a particular condition (watch negative and control negative) was counterbalanced across the two tested group groups (frequently active and infrequently active). The order of the conditions (watch neutral, watch negative, control negative) was random for each participant. We did not incorporate a "control neutral" condition because such an approach is unlikely to be used in everyday situations.

Before completion of the experimental task, participants underwent training on how to use the reappraisal strategy (i.e. reinterpret the meanings of pictures). They were taught to use two reappraisal procedures: (1) denying the reality of a depicted situation or (2) imagining a positive outcome of a depicted situation, similarly to the procedure described by Ochsner et al. (2004). Participants were free to use these methods interchangeably in order to alleviate the negativity of the presented pictures in the most efficient way. During this training, they performed several training trials with the assistance of the experimenter. Participants were asked to practice the reappraisal strategy aloud in order to allow the experimenter to provide them with feedback. Then, participants were taught how to approach the pictures in the control condition: they were asked just to watch them passively and let emotions naturally arise. The training session lasted until the experimenter was assured that the participant knew how to use the reappraisal strategy and how to approach the pictures in the control condition accurately.

The experimental session was administered in 6 blocks with 1-min

[2] The following NAPS pictures number were chosen: 101, 271, 495, 555, 595, 622, 646, 672, 687, 729, 745, 761, 763, 777, 787, 792, 804, 805, 808, 809, 814, 832, 835, 866, 879, 883, 903, 906, 927, 930, 934, 959, 961, 1130, 1156, 1303, 1331, 1342, 1343, 1348.

[3] The following NAPS pictures number were chosen: 1, 4, 23, 24, 26, 27, 28, 31, 33, 44, 48, 54, 71, 78, 254, 421, 422, 423, 429, 438, 447, 546, 698, 700, 722, 727, 739, 869, 886, 1100, 1103, 1127, 1246, 1250, 1252, 1259, 1260, 1261, 1275, 1305.

[4] The following NAPS pictures number were chosen: 5, 6, 8, 10, 16, 17, 29, 89, 93, 98, 116, 268, 269, 277, 280, 289, 291, 297, 299, 444, 449, 558, 713, 1084, 1089, 1101, 1104, 1110, 1239, 1243, 1248, 1256, 1266, 1277, 1281, 1290, 1293, 1295, 1296, 1298.

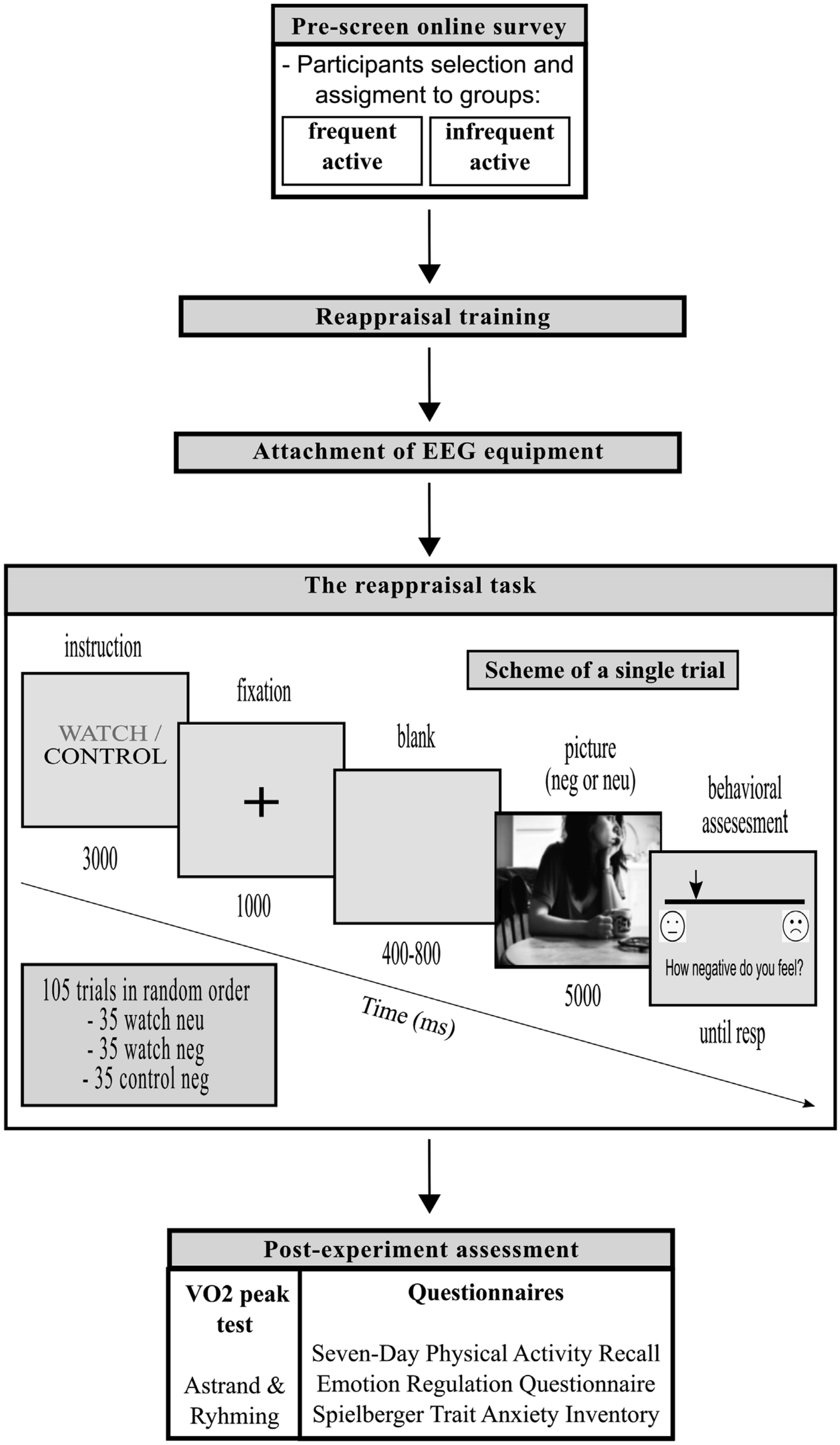

Fig. 1. The study diagram with the timeline of an example trial used in the study.

breaks between them. Blocks 1–5 contained 17 trials, whereas the last block contained 20 trials. Within each block, three experimental conditions - watch neutral, watch negative, control negative - were randomized on the trial-to-trial basis. Overall, the experimental session consisted of 105 trials, 35 trials for each condition. Fig. 1 presents the timeline of an example trial.1.

2.3. VO2 peak (peak oxygen uptake) protocol

To assess the physical work capacity of participants, maximal oxygen uptake (VO_2 peak) was indirectly estimated using the Åstrand-Rhyming cycle test, which assumes a linear relationship between heart rate (HR) and VO_2peak (Astrand & Ryhming, 1954). All participants performed a 6-min submaximal effort at a constant power on a cycloergometer (Ergoline, Germany). The pedaling rate during the test was 60 rpm. During the exercise, their heart rate (HR) was measured (Polar S610i, Finland). The power output was adjusted to the physical capability of each participant separately so that they should reach the target HR zone of 120–170 bpm at the end of the 6-min test. The mean HR for the last 2 min of stress (steady-state) was calculated and the absolute VO_2peak value was determined. The averaged loads that was used in the protocol was 87.98 ± 23.25 W (71 ± 16.85 W for the infrequent active group; 103.7 ± 16.25 W for the frequent active group).

2.4. Questionnaires

Participants were asked to complete three questionnaires (as described below) in order to collect information on their background characteristics: estimated average daily calorie expenditure (Seven-Day Physical Activity Recall, SDPARQ), tendency to use emotion regulation strategies (Emotion Regulation Questionnaire, ERQ) and, anxiety levels (Spielberger State Trait Anxiety Inventory, STAI). The data from the questionnaires allowed us to compare the two tested groups and explore the relationships between the participants' individual characteristics and the ability to control negative emotions by the reappraisal.

2.4.1. Seven-Day Physical Activity Recall (SDPARQ)

The SDPARQ questionnaire is a measure of the overall physical activity level of adults. It determines physical activity in metabolic equivalents (MET) based on the time spent on the following activities: sleeping, leisure and occupational physical activity for the 7-day period before the visit in the laboratory (Sallis, Buono, Roby, Micale, & Nelson, 1993). Participants indicated how many minutes they spent on physical activity of different intensities and how many hours they had slept in the week preceding the test (separately for weekdays and weekend). To estimate the metabolic equivalent of physical activity dose (METh/week), the hours devoted to physical activity (moderate, vigorous, or very-vigorous) were multiplied by the corresponding MET (4, 6, or 10, respectively) (for a detailed description of the MET calculation see: Ainsworth et al., 1993). To estimate total energy expenditure per day, sleeping time and light intensity activity is multiplied by 1 and 1.5 MET, respectively, and added to the activity dose. As our online prescreening questionnaire was employed only to assign participants to one of the two groups that differed in the frequency of exercise (frequently vs. infrequently), the SDPAR questionnaire was employed in order to quantify the levels of physical exercise that should allow exploration of the relationships between the physical activity levels and the ability to control negative emotions.

2.4.2. Emotion Regulation Questionnaire (ERQ)

The ERQ measures individual differences in the habitual use of two emotion regulation strategies: expressive suppression and cognitive reappraisal (Gross and John, 2003). Participants assessed to what extent they agree with the statements which reflects the use of these strategies (4 items for the expressive suppression strategy, e.g., "I control my emotions by not expressing them"; *Cronbach's* $\alpha = 0.72$ in the study and 6 items for the reappraisal strategy, e.g., "When I want to feel less negative emotion, I change the way I'm thinking about a situation"; *Cronbach's* $\alpha = 0.84$ in the study). Participants assessed the statements using the scale ranging from 1 ("strongly disagree") to 7 ("strongly agree"). Higher scores indicated greater tendency to use a strategy. The questionnaire was employed in order to determine to what extent participants were likely to use the reappraisal strategy and to what extent this preference might be related to the reappraisal efficacy in this study.

2.4.3. Spielberger State Trait Anxiety Inventory (STAI)

The STAI-trait questionnaire measures anxiety level as a personal trait (Spielberger, 1983). Participants assessed to what extent they experience different feelings, such as happiness, tension, self-confidence and disappointment (20 items in total; e.g., "I am a stable person"; "I feel content") using a scale ranging from 1 ("almost never") to 4 ("almost always") (*Cronbach's* $\alpha = 0.92$ in this study). Higher scores indicated greater anxiety and tendency to perceive situations as threatening and dangerous. The questionnaire was employed in order to test whether the anxiety might be related to the reappraisal efficacy in this study (Mennin et al., 2005).

2.5. Experimental procedure

The experimental procedure was compliant with the directives of the Helsinki Declaration and approved by the Jagiellonian University ethical board. Upon arrival at the laboratory, participants provided informed consent. They were then seated in an air-conditioned soundproof cabin and underwent in-depth training of the reappraisal usage.

After the training of the reappraisal, participants were seated approximately 70 cm directly in front of the computer screens and EEG equipment was attached; they performed the emotion regulation task, while their EEG was recorded.

Afterwards, participants underwent a VO2 peak protocol to estimate their level of cardiovascular fitness (see: Fig. 1 for the study diagram). Lastly, they were asked to complete the battery of 3 questionnaires and received the equivalent of €20 for participation. We administered the questionnaires at the end of the procedure, as otherwise they could influence the performance of the experimental task.

2.6. Electrophysiological recordings and preprocessing

The EEG signal was recorded at 256 Hz from 64 Ag/AgCl scalp electrodes, positioned at the standard 10–20 locations, mounted in an elastic cap, using the Biosemi Active Two recording system. Electrodes were initially referenced online to the Common Mode Sense electrode located at the C1 electrode. A horizontal and vertical electrooculogram (EOG) was recorded bipolarly using electrodes placed below and above the right eye and at the outer canthus of each eye, respectively. The electrode offset was kept within a range as recommended by BioSemi EEG User Guide (± 25 μV). Two additional electrodes were placed on participants' mastoids.

EEG data were analyzed using EMEGS software (Peyk, De Cesarei, & Junghöfer, 2011). The EEG signal was offline filtered using 0.1 Hz high-pass and 40 Hz low-pass zero-phase filters and then re-referenced to an averaged activity of all channels. Ocular artifacts were corrected using the Biosig toolbox and artifact rejection was then conducted using the method for statistical control of artifacts in high density EEG/MEG data (Junghöfer, Elbert, Tucker, & Rockstroh, 2000). This procedure (1) detects individual channel artifacts, (2) detects global artifacts, (3) replaces artifact-contaminated channels with spline interpolation, statistically weighted on the basis of all remaining channels and (4) computes the variance of the signal across trials to document the stability of the averaged waveform. The artifact rejection relies on the calculation of statistical parameters for the absolute measured amplitudes of potentials over time, their standard deviation over time, as well as on the determination of boundaries for each parameter. Afterwards, all trials were manually inspected to remove any remaining artifacts. On average, 15.25 (SD = 6.09) trials for each participant were removed. For each condition, the mean number of remaining trials after behavioral correctness analysis and EEG artifact rejection was as follows (mean ± standard deviation): watch neutral (29.79 ± 2.51); watch negative (30.31 ± 2.24); control negative (30.67 ± 2.34)[5]. Epochs of 200 ms before and 5000 ms post-stimulus onset were then extracted from the continuous EEG and baseline corrected according to the 150 ms time window before stimulus onset. Stimulus-locked ERP averages were computed individually for each participant for the experimental (control negative) and control (watch negative) conditions, separately.

2.7. LPP

LPP was defined as a sustained stimulus-locked positivity that develops approximately 400 ms after stimulus onset. Based on visual inspection of the grand-averaged ERP waveforms and in line with the previous literature, we found a prolonged LPP occurring 450–5000 ms after stimulus onset which reached its maximum at the Pz electrode site (Moran et al., 2013). Following the previous studies (e.g. Krompinger et al., 2008; Moran et al., 2013; Schönfelder et al., 2014; Wyczesany & Ligeza, 2017), we quantified the LPP in consecutive time windows which enabled us to assess the temporal dynamics of this component. The LPP was defined as the mean amplitude at Pz electrode site for each task condition separately in the following time windows: 450–1000 ms (LPP 1), 1000–2000 ms (LPP 2), 2000–3000 ms (LPP 3), 3000–4000 ms (LPP 4), 4000–5000 ms (LPP 5). The time windows that we chose are consistent with other studies that have investigated the temporal aspects of emotional control and which have presented pictorial stimuli for at least 5000 ms (e.g. Schönfelder et al., 2014; Strauss et al., 2015).

2.8. Data analyses

All statistical analyses were performed using SPSS Statistics version 21 (IBM, Armonk, NY, USA). First, all data were screened for normality and outliers. For the behavioral measure, reappraisal efficacy was defined as the difference between self-rated unpleasantness evoked by the pictures in the control condition (passive viewing) and in the experimental (reappraisal) condition. For the LPP measure, reappraisal efficacy was defined as the difference between mean voltage amplitude in the control condition and in the experimental condition in each LPP time window (1–5) separately. [6]

2.8.1. Behavioral data

To test the difference in reappraisal efficacy between frequently and infrequently active groups, we performed an ANOVA with Task Condition as a within-subject factor (levels: passive viewing, reappraisal) and Group as a between-subject factor (levels: infrequently, frequently active).

2.8.2. LPP analyses

To test the difference in reappraisal efficacy between frequently and infrequently active groups, we performed a series of ANOVAs with Task Condition as a within-subject factor (levels: passive viewing, reappraisal) and Group as a between-subject factor (levels: infrequently, frequently active) in each LPP time window (1–5) separately.

2.8.3. Correlational analyses

Using Pearson's correlation coefficient, the behavioral and ERP indices of reappraisal efficacy (calculated as the difference between the watch negative minus the control negative conditions) were correlated with participants' background characteristics: physical work capacity (VO2peak), average daily energy expenditure (SDPARQ), trait of anxiety (STAI), and tendency to use emotional control strategies (ERQ). To account for the multiple comparisons, all correlations were corrected using the false discovery rate (FDR) procedure (Benjamini & Hochberg, 1995). The critical p value for all correlations was $p < .05$.

3. Results

Table 2 presents the mean self-rated unpleasantness of the pictures and the mean voltage amplitude of LPP in each task condition and group. The Fig. 2 shows the average ERP waveforms[7].

3.1. Behavioral data

Analysis revealed a main effect of Task Condition: $F(1,50) = 34.26$, $p < .001$, $\eta p2 = .41$. Participants reported more unpleasant feelings after the passive viewing condition (36.90 ± 2.45) relative to the reappraisal condition (26.15 ± 2.39). The main effect of Group, and the interaction between Task Condition and Group were non-significant: $F(1,50) = 0.74$, $p = .393$, $\eta p2 = .02$ and $F(1,50) = 0.7$, $p = .406$, $\eta p2 = .01$, respectively.

3.2. ERP analyses

3.2.1. LPP 1

Analysis revealed a main effect of Task Condition: $F(1,50) = 4.09$, $p = .049$, $\eta p2 = .08$. The amplitude of LPP 1 in response to negative pictures in the passive viewing condition (4.35 μV ± 2.79) was significantly higher compared with the reappraisal condition (3.83 μV ± 2.64). The main effect of Group, and the interaction between Task Condition and Group were non-significant: $F(1,50) = 0.13$, $p = .720$, $\eta p2 < .01$ and $F(1,50) = 0.03$, $p = .956$, $\eta p2 < .01$, respectively.

3.2.2. LPP 2

Analysis revealed a main effect of Task Condition: $F(1,50) = 4.23$, $p = .045$, $\eta p2 = .08$. The amplitude of LPP 2 in response to negative pictures the during passive viewing condition (1.79 μV ± 3.35) was significantly higher compared with the reappraisal condition (1.11 μV ± 2.96). The main effect of Group, and the interaction between Task Condition and Group were non-significant: $F(1,50) = 0.87$, $p = .769$, $\eta p2 < .01$ and $F(1,50) = 0.28$, $p = .869$, $\eta p2 < .01$, respectively.

3.2.3. LPP 3

Analysis revealed a main effect of Task Condition: $F(1,50) = 4.84$, $p = .032$, $\eta p2 = .09$. The amplitude of LPP 3 in response to negative pictures in the passive viewing condition (1.34 μV ± 3.53) was significantly higher compared with the reappraisal condition (0.69 μV ± 3.03). The main effect of Group, and the interaction between Task Condition and Group were non-significant: $F(1,50) = 0.76$, $p = .387$, $\eta p2 = .02$ and $F(1,50) = 0.26$, $p = .614$, $\eta p2 < .01$, respectively.

3.2.4. LPP 4

The main effect of Task Condition was non-significant: F

[5] Note that 12 trials are sufficient to obtain a reliable and stable LPP component in reappraisal procedures (Moran et al., 2013).

[6] Following the approach of other studies (Moser et al., 2014; Ochsner et al., 2004), and for the sake of the clarity of the text, the condition of "watch neutral" served as a filler condition to buffer against possible habituation to the negative images and, as such, this condition was beyond the scope of the present study and did not taken into account in the analyses. However, to show that there was an expected difference in emotional response in response to neutral vs negative pictures in both behavioral and LPP measures, we report appropriate statistics in a footnote of the result section.

[7] Significant differences in response to neutral and negative picture were observed both in behavioral data [$t(51) = 14.12$; $p < .01$] and in all of the analyzed LPP time windows: LPP1 [$t(51) = 7.57$; $p < .01$]; LPP2 [$t(51) = 3.98$; $p < .01$]; LPP3 [$t(51) = 2.74$; $p < .01$]; LPP4 [$t(51) = 2.08$; $p = .04$]; LPP5 [$t(51) = 2.95$; $p < .01$].

Table 2
Behavioral and ERP results (M ± SD) by condition.

	Infrequently active	Frequently active	Total
Reported unpleasantness[a]			
Watch negative	34.19 ± 17.58	39.60 ± 17.73	36.90 ± 17.70
Control negative	24.97 ± 17.40	27.31 ± 17.31	26.15 ± 17.22
LPP 1 (450–1000 ms)[a]			
Watch negative	4.22 ± 2.66	4.49 ± 2.95	4.36 ± 2.79
Control negative	3.70 ± 2.82	3.94 ± 2.49	3.82 ± 2.64
LPP 2 (1000–2000 ms)[a]			
Watch negative	1.88 ± 3.03	1.69 ± 3.70	1.79 ± 3.35
Control negative	1.26 ± 2.94	0.96 ± 3.01	1.12 ± 2.96
LPP 3 (2000-3000ms)[a]			
Watch negative	1.64 ± 2.90	1.03 ± 4.10	1.34 ± 3.53
Control negative	1.14 ± 2.57	0.23 ± 3.42	0.69 ± 3.03
LPP 4 (3000-4000ms)			
Watch negative	1.33 ± 2.96	1.00 ± 4.39	1.17 ± 3.71
Control negative	1.77 ± 3.21	0.55 ± 4.07	1.16 ± 3.68
LPP 5 (4000-5000ms)[b]			
Watch negative	1.47 ± 2.77	1.41 ± 5.07	1.43 ± 5.07
Control negative	1.62 ± 3.29	0.20 ± 4.82	0.91 ± 4.15

Note.: ERPs were measures as mean amplitude in µV.
[a] , significant difference between watch negative and control negative conditions regardless of the group.
[b] , significant interaction between experimental condition and the group.

$(1,50) = 0.87$, $p = .769$, $\eta p2 < .01$. The main effect of Group, and the interaction between Task Condition and Group were non-significant as well: $F(1,50) = 0.64$, $p = .429$, $\eta p2 = .01$ and $F(1,50) = 1.66$, $p = .203$, $\eta p2 = .03$, respectively.

3.2.5. LPP 5

Task Condition and Group factors were not significant: $F(1,50) = 2.54$, $p = .117$, $\eta p2 < .05$ and $F(1,50) = 0.44$, $p = .510$, $\eta p2 < .01$, respectively; however, there was a significant interaction between these two factors: $F(1,50) = 4.51$, $p = .039$, $\eta p2 = .08$. The post-hoc test revealed that the difference between the passive viewing and reappraisal conditions was non-significant for the infrequently active group (1.48 µV ± 2.77 for passive viewing and 1.62 µV ± 3.29 for reappraisal): $F < 1$, whereas the difference was significant for the frequently active group (1.41 µV ± 5.07 for passive viewing and 0.20 µV ± 4.82 for reappraisal): $F(1,50) = 6.91$, $p = .01$, $\eta p2 = .12$.[8]

3.3. Correlations

Table 3 depicts the correlation matrix for the measures of the reappraisal efficacy and the background characteristics of participants.

The reappraisal efficacy in the LPP5 positively correlated with the SDPAR scores ($r = 0.35$, $p < .05$). The more physically active the participants were, the greater the reappraisal efficacy they demonstrated. The reappraisal strategy did not correlated significantly with either the genetic predispositions to the physical exercise (i.e., VO2max), the level of anxiety (i.e., STAI), or the habitual use of ER strategies (i.e., ERQ1 and ERQ2).

4. Discussion

The study investigated the relationship between the frequency of the physical exercise and the efficacy of controlling negative emotions by reappraisal. Two groups of participants that differed in the frequency of the physical exercise (more than 3 times per week vs. less than one time per week) were matched in terms of the type and the intensity of the practiced exercise (which was aerobic exercise at moderate intensity). Both groups performed the experimental task that required them to control negative emotions. Participants were presented with pictures and in the case of negative pictures they were

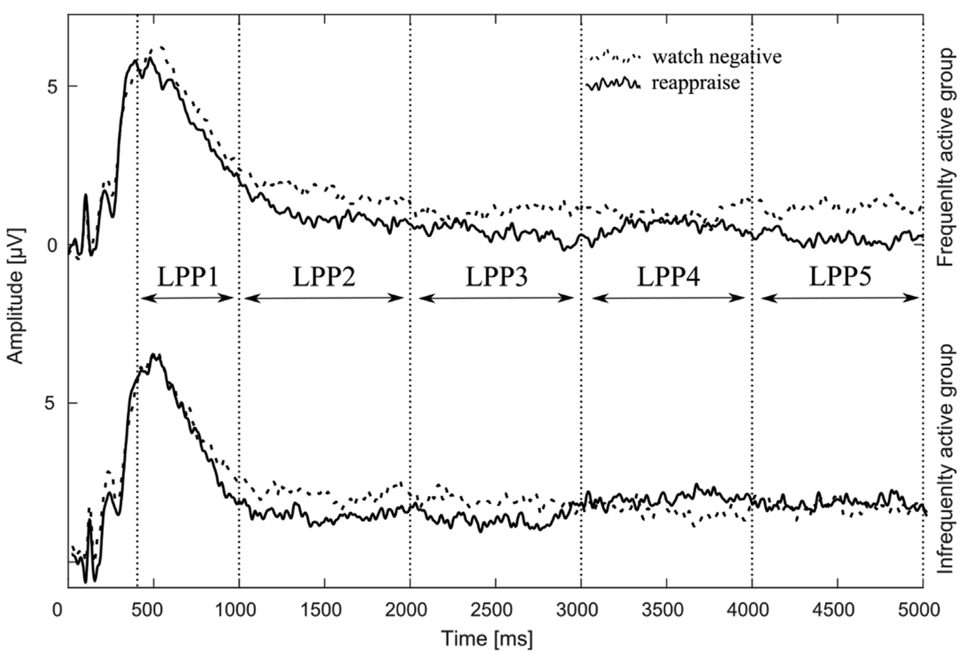

Fig. 2. Stimulus-locked ERP waveforms at Pz electrode. Grand-averaged ERP waveforms are shown for the watch negative condition (dotted line) and the reappraise condition (solid line) in the frequently active group (upper panel) and the infrequently active group (lower panel). Time windows for the consecutive parts of the LPP component are marked. Each panel shows amplitude in microvolts on the y axis and time in milliseconds on the x axis.

[8] An additional analysis was set out to test whether anxiety trait measured by STAI trait questionnaire confounded with the measurement of the physical activity in this study. To this aim, we performed a 2 (Task Condition: passive viewing, reappraisal) x 2 (Group: infrequently, frequently active) ANCOVA analysis with the factor Anxiety as a covariate. The analysis showed that the interaction between Task Condition and Group is significant when controlling for the level of anxiety: $F(1,49) = 3.93$, $p < .05$, $\eta p2 = .07$. The post-hoc test revealed that a difference between the passive viewing and reappraising was non-significant for the infrequently active group: $F < 1$, whereas it was significant for the frequently active group: $F(1,49) = 6.38$, $p = .02$, $\eta p2 = .11$ We thank the Reviewer for recommending this analysis.

Table 3
Correlations between the measures of the reappraisal efficacy and the background characteristics of participants.

	SDPAR	VO2peak	STAI	ERQ1	ERQ2
EoR Beh	.092	.190	-.068	.158	-.079
EoR LPP1	.093	.083	-.092	.038	-.059
EoR LPP2	.082	.046	-.087	.031	-.014
EoR LPP3	.137	.112	-.159	.114	-.027
EoR LPP4	**.275***	.063	-.061	.085	.086
EoR LPP5	**.349****	.117	-.138	.194	-.076

Note: *p < .05 non-corrected, **p < .05, FDR corrected; EoR Beh – efficacy of reappraisal as assessed by behavioral measure; EoR LPP 1–5 – efficacy of reappraisal as assessed by LPP; SDPAR – physical activity level; VO2peak-maximal oxygen uptake; STAI – anxiety trait; ERQ1 – tendency to use reappraisal; ERQ2 – tendency to use suppression.

asked either to watch them passively (control condition) or to reappraise them (i.e. downregulate negative feelings; experimental condition). The effect of reappraisal (difference between the two conditions; reappraisal efficacy) was measured by both behavioral and ERP measurement (i.e. self-reported unpleasantness of pictures and LPP, respectively). Below, we discussed the present findings.

4.1. Behavioral data

We observed the classic effect of the reappraisal in the behavioral data: participants reported less unpleasant feelings after reappraising negative emotions evoked by the negative pictures compared with just passively viewing the negative pictures. This effect is in line with the literature (that was reported in the previous studies on the reappraisal (McRae et al., 2009; Ochsner et al., 2004; Wyczesany & Ligeza, 2017). At the same time, however, contrary to our expectations, we did not find any between-group differences in the reappraisal efficacy. The self-ratings of unpleasantness of negative pictures did not differ between the frequently active group and the infrequently active group. As such, we did not find evidence for the relationship between the frequency of the physical exercise and the efficiency of the reappraisal in the behavioral measure.

It should be noted, however, that self-reporting as a behavioral index of reappraisal efficacy raises some concerns. Since participants in the reappraisal condition are explicitly asked to reduce negative feelings induced by a picture, they might adjust their self-rating responses to conform to the experimenter's expectations. Moreover, individuals might experience and evaluate their feelings with different intensity depending on their personal characteristics, which may introduce additional noise to the measurement. Overall, it might be argued that self-reporting is not a reliable measure of the reappraisal efficacy and more objective measures of reappraisal efficacy are highly desirable (for a detailed discusssion of an argument see: Wyczesany & Ligeza, 2017).

4.2. LPP data

We employed the measurement of the Late Positive Potential (LPP) in order to provide an objective and reliable measure of the reappraisal. The LPP is a well-established marker of emotional processing and reappraisal efficacy which should enable us to track online the cognitive processes underlying the reappraisal and learn more about the relationship between the frequency of the physical exercise and the reappraisal efficacy (Hajcak & Nieuwenhuis, 2006; Schupp et al., 2000). Since the LPP allows measurement of an emotional response, it should have revealed between-group differences in the reappraisal efficacy. We found the prolonged LPP (400–5000 ms, mostly pronounced at electrode Pz) in the ERP data. When measuring the LPP we incorporated the approach as suggested by the previous studies (e.g. Schönfelder et al. (2014)) and divided the LPP into five consecutive time windows: LPP1 (400–1000 ms), LPP2 (1000–2000 ms), LPP3 (2000–3000 ms), LPP4 (3000–4000 ms), LPP5 (4000–5000 ms). This enabled us to measure the dynamics of the emotional response across the frequently active and the infrequently active groups. In line with the previous studies that investigated the reappraisal efficacy using the LPP measurement, the LPP for negative pictures was lower (i.e. less positive) when participants reappraised negative pictures compared to just passively viewing them (e.g. Krompinger et al., 2008; Moran et al., 2013; Schönfelder et al., 2014; Wyczesany & Ligeza, 2017). This effect was observed for most of the analyzed LPP time windows (LPP1, LPP2, LPP3) and suggests that all participants were efficient in reappraising negative pictures at the beginning of the picture presentation. What is more, we observed the interaction between the task condition (reappraisal vs. passive viewing) and the group (infrequently vs. frequently active) in the last portion of the LPP: the LPP5 was substantially reduced in the reappraisal condition as compared to the control condition only in the frequently active group and no such an effect was found in the infrequently active group (this interaction was still significant when the level of anxiety included in the analysis). To sum up, the measurement of the LPP in some consecutive time windows allowed us to observe the effect of the physical exercise frequency at the final stage of the reappraisal process. Although currently only a speculation, the observed pattern of results suggests that the frequency of the physical exercise substantially modulate the outputs of the reappraisal process. Taken together, the LPP (but not the behavioral data) supports the idea that the frequency of physical activity might be positively related to better ability of controlling negative emotions.

4.3. Correlation analyses

To gain deeper understanding of the relationship between the frequency of physical activity and the ability to regulate negative emotions, we measured participants' background characteristics related to their overall efficacy of controlling negative emotions (anxiety trait measured by STAI trait questionnaire; tendency to use reappraisal on a daily basis measured by Emotion Regulation Questionnaire), and those related to participants' physical activity levels (i.e. measured by SDPARQ), and physical work capacity measured by VO2peak test). In addition, the VO2 peak test allowed us also to confirm increased physical work capacity in more active participants.

As displayed in the descriptive statistics, the frequently active group was characterized by a lower anxiety score (STAI trait questionnaire), greater physical activity levels (SDPARQ), and greater physical work capacity (VO2peak test, (see: Table 1). Because the groups differed in their background characteristics, it might well be that individual differences related to efficacy of controlling negative emotions affected their task performance and, as such, moderated the relationship between the physical exercise and the efficacy of reappraisal. In order to account for a potential influence of participants' background characteristics on the reappraisal efficacy, we explored the correlations between the behavioral and ERP indices of the reappraisal efficacy and tendency to use reappraisal and anxiety trait. We did not find any significant correlations between the indices of reappraisal efficacy (difference in response to passively attend vs reappraised pictures in both self-reports and LPP measure) and: 1) participants' tendency to use reappraisal on a daily basis, and 2) the anxiety trait. The pattern of results suggests that none of the aforementioned measures was related to the ability to control negative emotions in this study and as such the relationship between the physical exercise and the efficacy of reappraisal as observed in our study was not moderated by these factors.

As stated in the Introduction, still little is known about the relationship between the physical exercise and cognitive control of emotions. In order to learn more about the relationship between the efficacy of reappraisal and the physical exercise, we measured the participants' background characteristics related not only to the physical exercise levels (SDPARQ) but also to physical work capacity (VO2peak).

Although no significant correlation was found in case of the physical work capacity of participants, we found a significant correlation between the physical activity levels and the reappraisal efficacy in the LPP5[9]. This finding is in line with the effect of the frequently active group observed in the LPP5. Taken together of all additional measures that were incorporated into out correlational analysis, only the level of physical activity was associated with improved ability to control negative emotions.

Overall, both correlation results based on the SDPARQ questionnaire and the between group comparisons based on the pre-screeing questionnaire show that more frequent physical activity is associated with better ability to regulate negative emotions (as assessed by LPP). These two measures not only point to the conclusion, but also seem to be complementary to each other. Our pre-screening questionnaire allowed for a precise assignment of participants to frequently active and infrequently active groups, matching participants in both groups in terms of type of exercise practiced. The SDPARQ allowed us to collect continuous data reflecting physical activity level that could be correlated with the reappraisal efficacy indices. The study also suggests that physical work capacity (VO2peak) itself is not related to efficacy of controlling negative emotions. This suggest, that improved reappraisal efficacy results from other psycho-physiological factors that are also related to increased physical activity (like improved self-efficacy after completion of an effort, time-out from daily stressors, or elevated endorphin production, just to name a few).

4.4. Limitations

There are several limitations to this study. Since the sample of participants in the study was composed of females only, the study's findings cannot be generalized to the overall population (for a rationale to test females only, see *Footnote 1*).

Further, we did not observe any difference in the effects of the reappraisal in the behavioral measurement. The frequently active and the infrequently active group did not differ in their self-rated feelings. This might raise some concerns about the validity of the results presented in the article. At the same time, however, no between-group difference in the self-reports might be a consequence of the subjective nature of the behavioral measurement which was self-rating. Specifically, it might well be that the participants tried to adjust to the expectations of the experiment and either overestimate or underestimate their self-ratings. We believe that the experimental manipulation is this study was valid, because we found a significant between-group difference in the LPP component which is commonly regarded as the objective measure of the reappraisal efficacy.

Further, as our study is cross-sectional, we cannot draw any direct conclusions about the influence of the physical activity on the ability to control emotions. Although we found no associations between physical activity and other, possibly confounding variables (anxiety state, emotion regulation tendencies), it cannot be excluded that other variables influenced the difference in LPP across the two tested groups but we did not measure them in this study. A study in which participants are randomly assigned to frequently active and infrequently active groups is necessary to determine whether exercise indeed influences the ability to reappraise. Our research may be a premise for undertaking such research in the future studies. Future studies should also include additional measures of emotional response (heart rate, electro-dermal activity) and possibly utilize less suggestive instruction for reappraisal procedure.

[9] A significant correlation between physical activity levels and reappraisal efficacy measured in the LPP4 time window was significant without FDR correction.

End notes

To conclude, this cross-sectional study suggests that being physically active might be associated with a greater ability to control negative emotions via reappraisal. However, the differences between frequently and infrequently active participants seem to be small and observable only when neural measures of reappraisal efficacy are employed (here LPP measurement).

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