Expectations affect psychological and neurophysiological benefits even after a single bout of exercise

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Abstract

The study investigated whether typical psychological, physiological, and neurophysiological changes from a single exercise are affected by one's beliefs and expectations. Seventy-six participants were randomly assigned to 4 groups and saw different multimedia presentations suggesting that the subsequent exercise (moderate 30 min cycling) would result in more or less health benefits (induced expectations). Additionally, we assessed habitual expectations reflecting previous experience and beliefs regarding exercise benefits. Participants with more positive habitual expectations consistently demonstrated both greater psychological benefits (more enjoyment, mood increase, and anxiety reduction) and greater increase of alpha-2 power, assessed with electroencephalography. Manipulating participants' expectations also resulted in largely greater increases of alpha-2 power, but not in more psychological exercise benefits. On the physiological level, participants decreased their blood pressure after exercising, but this was independent of their expectations. These results indicate that habitual expectations in particular affect exercise-induced psychological and neurophysiological changes in a self-fulfilling manner.

Keywords: expectation, exercise, EEG, placebo effect, mental health, mindset

Introduction

"Exercising makes you feel better." This popular statement is supported by substantial research demonstrating potentially health-relevant changes brought about by single sessions of physical exercise (acute exercise), not only on a psychological level (e.g., enjoyment, improved mood and reduced anxiety; Ensari et al., 2015; Liao et al., 2015; Raedeke, 2007) but also on physiological (e.g., reduced blood pressure; MacDonald, 2002) and neurophysiological levels (e.g., increased brain alpha activity; Crabbe & Dishman, 2004). Sometimes, however, exercising individuals experience only little or none of these benefits, as the benefits also depend on personal, situational, or exercise-related characteristics (e.g., Rocheleau et al., 2004). For example, in contrast to people who exercise regularly, non-exercising individuals often barely improve their mood from a single session of moderate exercise (Hoffman & Hoffman, 2008). Due to a lack of "feel-good experiences," individuals may reduce physical activity levels in the long run, with all its consequences on health (Rhodes et al., 2009). Therefore, it is important to better understand the factors that influence the benefits of acute exercise. Previous research focused primarily on task characteristics such as exercise intensity or duration when examining influencing factors of exercise benefits (Ekkekakis et al., 2011). In doing so, these studies paid little attention to the fact that psychological factors such as beliefs and expectations might also critically influence those benefits.

It is well known that beliefs and expectations (also termed "mindsets" in some studies) selectively influence information processing as well as resulting experiences, actions, and responses (Crum et al., 2013). Most prominently, individuals' expectations of treatment benefits (outcome expectations) have been shown to play a powerful role in shaping mental and physical health in medical placebo research (for a review, see Price et al., 2008). Decades of medical research has shown that such outcome expectations influence a wide range of disease states (e.g., depression, addiction, and pain) and physiological functions (e.g., respiratory, cardiovascular, autonomic, immune, gastrointestinal, motor, endocrine) (Enck et al., 2013). Apart from medical placebo research, psychological research has lately accumulated evidence that expectations or beliefs towards behavioral outcomes also affect mental and body function in everyday life. This has been shown, for instance, in the domains of stress (Crum et al., 2013), nutrition (Crum et al., 2011), and aging (Levy et al., 2002). Accordingly, more and more researchers suggest systematically and proactively harnessing the effects of beliefs and expectations on health and well-being in more diverse fields (Crum & Phillips, 2015).

Although the role of beliefs and expectations in exercise health benefits is as yet little understood, initial evidence suggests that individuals' health benefits from exercise might be significantly driven by their own expectations (Crum & Langer, 2007; Desharnais et al., 1993; Helfer et al., 2015). With respect to regular (chronic) exercise, some studies suggest that raising expectations regarding exercise benefits can increase actual psychological benefits such as self-esteem improvements (Desharnais et al., 1993) and physiological benefits such as weight and blood pressure reductions (Crum & Langer, 2007). However, several studies have failed to replicate such effects (e.g., Stanforth et al., 2011). A recent experimental study investigating effects after acute exercise found participants to improve their mood more strongly following a light 10 min cycling exercise when the researchers induced an expectation that "exercise often results in good moods" (Helfer et al., 2015). Besides this study, however, little is known about the acute effect of such expectations in longer, more intense, and health-relevant exercises consistent with the recommendations of major health organizations (e.g., United States Department of Health and Human Services & Physical Activity Guidelines Advisory Committee [USDHHS & PAGAC], 2008). Further, nothing is known about effects manifesting at the physiological and neurophysiological level, as have been investigated in medical placebo research. A description of effects at the physiological and neurophysiological level would enrich our understanding of the psychological control individuals have over their immediate well-being and health.

The literature on this topic has examined two different types of expectations: experimentally induced expectations and (naturally occurring) habitual expectations. Most previous studies concerned with exercise-related health benefits have investigated the effect of experimentally induced expectations, such as those described in the previous paragraph (e.g., Crum & Langer, 2007; Desharnais et al., 1993; Helfer et al., 2015). However, ad hoc induced expectations involving verbal persuasion often do not reflect or even contradict a person’s previous experience. In contrast to artificially induced expectations, habitual expectations that reflect previous experience (e.g., from exercising) or cultural beliefs have only rarely been studied in this context, and the evidence is inconclusive (Berger et al., 1998; O'Halloran et al., 2002). Furthermore, little is known about the interplay between habitual expectations and induced expectations, that is, whether and to what extent it is possible to overwrite a person’s negative habitual beliefs and expectations concerning exercise benefits by inducing positive expectations.

The present study therefore examined whether (1) habitual expectations and (2) experimentally induced expectations influence acute health effects of a single session of exercise. To investigate this question, we used a 30-minute exercise session of bicycling at moderate intensity, as such exercise sessions are consistent with recommendations for health benefits by major health organizations (e.g., USDHHS & PAGAC, 2008) and known to induce feel-good experiences (Berger & Motl, 2000). Due to the power of beliefs and expectations in influencing psychological, physiological, and neurophysiological outcomes in various other health-related domains, we selected measures that indicated potential health-related benefits of acute exercise not only on psychological levels (enjoyment, mood, anxiety) but also on physiological (blood pressure) and neurophysiological levels (brain alpha activity).

Methods

Design and Hypotheses

Two different kinds of exercise-related expectations were examined: (a) habitual expectations and (b) experimentally induced expectations. Habitual exercise expectations were assessed by questionnaire. Induced exercise expectations were tested experimentally. Participants were randomly assigned (stratified by gender) across four conditions (*Enhanced Expectation* [*n* = 18], *Expectation* [*n* = 20], *Control 1* [*n* = 19], or *Control 2* [*n* = 19]). Directly before the beginning of a cycling exercise, they were shown one of four short multimedia presentations inducing different expectations of the exercise benefits. All of these media presentations were approximately 3 min in length and consisted of spoken words by a creditable speaker with corresponding pictures (similar to those used in previous studies, e.g., Crum et al., 2013). The multimedia presentations in the *Enhanced Expectation* and *Expectation* conditions aimed to induce positive outcome expectations regarding the subsequent exercise ("According to recent research this exercise is perfectly suitable for improving your immediate well-being"), with the Enhanced Expectation presentation aiming to induce an even stronger expectation by additionally focusing on the compression shirt worn by all participants ("Wearing this shirt will enhance physical capacity and increase exercise benefits"). The film clip in *Control 1* (No Expectation) condition was designed to *not* induce a particular expectation, as it only contained information regarding the investigation and electroencephalography (EEG) measurement that had already been given to all participants prior to the experiment. The film clip in *Control 2* (No-Effect Expectation) condition aimed to induce a more neutral outcome expectation ("According to recent research this exercise is not suitable for improving your immediate well-being, since it is too short and too weak"). We used this second control condition because it seemed difficult to completely rule out the effect of pre-existing positive exercise expectations with *Control 1* (when not inducing a particular expectation). Therefore, we introduced a No-Effect Expectation condition (Control 2) designed to involve less positive outcome expectations as an additional control condition (similar to the hidden treatment paradigm used in placebo research; see Colloca et al., 2004). Detailed content of the multimedia film clips can be found in the supplementary material available online (Table S1).

We predicted that participants with more positive expectations would benefit more from the exercise, not only regarding its psychological benefits but also with respect to potentially health-relevant physiological and neurophysiological changes. Regarding habitual expectations we predicted that participants with more positive expectations would yield greater exercise benefits. Similarly, regarding induced expectations we predicted that groups with positive expectations (*Enhanced Expectation* and *Expectation*) would yield greater benefits (1) than the *Control 1* and (2) *Control 2* conditions. Furthermore, we predicted (3) that the group with an enhanced positive expectation (*Enhanced Expectation)* would yield stronger exercise benefits than the group with a standard positive expectation (*Expectation*).

Participants

Participants were recruited by announcement in local newspapers and at universities in [name deleted to maintain the integrity of the review process]. During a telephone interview, we prescreened participants for current and past physical activity levels. We only included individuals who neither were engaging in substantial physical activity currently (≤ 60 minutes/week) nor had engaged in substantial amounts of regular exercise in the past (no engagement in sport clubs or competitions). The reason for selecting exclusively sedentary individuals was associated with our consideration that these subjects could derive particular benefit from the induction of positive exercise-related expectations in terms of health-related outcomes. Additionally, we screened participants for good command of the German language, relevant health problems, drug abuse, and right-handedness. Right-handedness was chosen as a criterion as a means of ruling out potential influences on EEG measurements. Since we were aiming for a sufficiently naive sample, we only included individuals with majors or minors other than psychology, medicine, biology, or sport science. To avoid bias, we did not disclose the true aim of the study to individuals until completion of the study. Instead, participants were informed that the study aim was to investigate neurophysiological and psychological mechanisms during physical activity. All participants gave their written informed consent and were compensated for participation with 20 €. The study was approved by the University Ethics Committee and was in accordance with the latest revision of the Declaration of Helsinki.

We determined sample size using G-Power (Faul et al., 2007) on the basis of effect estimates from previous studies (e.g., Crum & Langer, 2007: medium to large effects of expectations in the context of physical activity). For G-Power calculations, we assumed a medium effect size (group comparison between *Enhanced Expectation* vs. *Expectation* condition). The analyses showed that $N = 17$ per group or $N = 68$ overall are necessary to detect such an effect with a power of at least .80 ($\alpha = 0.05$). As we expected 30 % of the potential participants to decline to participate or fail to participate due to other reasons (e.g., illness), we planned to stop participant recruitment once we reached approximately 100 eligible individuals. A total of 210 participants were screened for eligibility, 102 of whom did not meet the inclusion criteria. Of the 108 eligible participants, 78 individuals decided to participate and completed the study. As the EEG files of two participants were damaged, we analyzed data from 76 participants between 18 and 32 years (age ± *SD*: 21.89 ± 2.87; 20 males). The final sample ($N = 76$) allowed for the detection of medium-sized effects (f = 0.23; $\alpha = .05$; power = .80). Baseline study groups in the final sample did not differ in age, BMI, preferences for cycling, levels of exercise, daily activity, fitness, habitual expectation, or relevant baseline variables except for fatigue ($p = .002$; see Table 1).

Procedure

The study took place in the laboratory of [name deleted to maintain the integrity of the review process], from October 2012 to March 2013. During recruitment, participants were told to be rested when participating in the experiment and to refrain from exercise and alcoholic or caffeinated beverages for 24 hours beforehand. Two experimental sessions were conducted. In the first session, we asked each subject to participate in a fitness (cycling) test to identify the individual level of moderate intensity for the subsequent second session (main experiment). After assessing the participants' habitual exercise expectations (Fuchs, 1994) via questionnaire, we instructed them to take a standardized fitness test on an ergometer (Ergo-Bike Medical8i_2, Daum, Germany). The temperature in the laboratory was kept constant (20 °C, 68 °F). Following the fitness assessment, participants were randomly assigned to the induced expectation conditions.

A sketch of the experimental protocol on the second test day (main experiment; on average, 33.8 days after the fitness assessment) is depicted in Figure 1. Upon arrival at the laboratory, each participant was given a sleeveless compression shirt of a well-known sports brand to be worn during the test. Participants were seated and then completed a set of questionnaires assessing their baseline mood (POMS; Profile of Mood States; Bullinger et al., 1990) and anxiety (STAI; State-Trait Anxiety Inventory; Laux et al., 1981) as well as their sleep duration, drug intake, and nicotine, caffeine, and alcohol consumption in the previous 24 hours. Thereafter, we recorded their baseline resting blood pressure and EEG activity (eyes closed, 5 min) while sitting. Following the experimental expectation induction via multimedia film clip (for details, see below), participants completed a 2-minute warm-up and then a 30-minute exercise session on the bicycle ergometer with moderate intensity. After the exercise, participants were seated again. We measured systolic and diastolic blood pressure after 1 min (POST1), 10 min (POST10), 20 min (POST20), and 30 min (POST30), and we recorded EEG 2–7 min (POST2), 15–20 min (POST15), and 30–35 min (POST30) post exercise. Additionally, we assessed mood (POMS) and anxiety (STAI) within 7–14 min post exercise and exercise enjoyment (PACES; Physical Activity Enjoyment Scale; Jekauc et al., 2013) within 22–29 min after completion of the exercise.

Both the investigator in the laboratory and the participants were blinded with regard to the treatment assignment. To ensure blinding, participants were not informed about the true purposes of the media presentation, but were instead told that the film provided further information about the study background. Furthermore, we ensured that research assistants conducting the measurements were unable to identify the group assignments of participants by preventing them from seeing and hearing the media presentation (all participants wore headphones while listening to the media presentation). All researchers who interacted with the participants remained blinded until final data analysis.

Habitual Exercise Expectations

To assess participants' habitual exercise expectations (outcome expectations) regarding exercise-induced health effects, we used the two validated subscales (1) *physical and mental health* and (2) *physique and weight* from the Exercise Outcome Expectation Questionnaire (Fuchs, 1994). The two subscales consisted of 7 and 2 items, respectively (e.g., "If I exercise regularly, I will feel more comfortable"), all of which were scored on a 5-point Likert scale. A sum score was calculated (range: 9–45), with a higher score indicating greater expectations of positive health effects following exercise. In the current sample, the internal consistency (Cronbach's α) of the 9 items was .86.

Fitness Test and Acute Exercise in the Experiment

To assess physical fitness, we used a standardized incremental exercise test on a bicycle ergometer (Ergo-Bike Medical8i_2, Daum, Germany) starting at 60 watts with increases of 20 watts every minute until volitional exhaustion. Participants were instructed to keep the cadence constant at approximately 75 pedal rotations per minute (RPM). Before the test, the saddle height was individually adjusted to allow comfortable sitting. We used maximal power output (P_{max}) relative to body weight as a measure for physical fitness (for financial reasons, as substitute to a spiroergometry with lactate assessment). On the basis of the general linear relationship between oxygen uptake (VO_2) and power output on a bicycle ergometer (Wasserman, 2012), P_{max} can be considered a valid and reliable estimate for $VO_{2\,max}$ (e.g., Hawley & Noakes, 1992). Moderate intensity in the main experiment (30 minutes cycling on the same ergometer with a cadence of approximately 75 RPM) was set to 40 % of P_{max} of participants' individual fitness test results. We selected this level of moderate intensity (40 % of $P_{max)}$ as a level just below lactate threshold on the basis of a comprehensive laboratory database with 2958 fitness assessments from trained and untrained individuals (Radlabor GmbH, Freiburg, Germany) showing that the 95 % confidence interval of the lactate threshold ranged from 41.1 %–65.1 % (on average 53.1 %). During the main experiment, we monitored rate of perceived exertion (RPE: 13.18 ± 1.28; Borg, 1998) and heart rate (136.01 ± 15.67; 68.82 ± 7.69 % of each participant's age-predicted heart rate maximum) with the Polar RS800CX. Note that due to the limitations of the fitness assessment applied (e.g., no direct measurement of individual lactate thresholds), three participants reported intensity levels that can be considered vigorous according to most classifications (≥ 80 % of their maximum heart rates). We checked whether these outliers influenced our results. This was not the case. All results we report here for all tested subjects remained unchanged when these three participants were excluded from the analyses.

Measures

Psychological Measures. As measures for state anxiety and mood, we used two scales applied extensively in the exercise literature (e.g., Ekkekakis & Petruzzello, 1999), namely the STAI (state anxiety subscale; Laux et al., 1981) and the POMS (Bullinger et al., 1990). The German STAI state anxiety subscale consists of 20 items asking how the respondent feels "right now, at this moment." The German version of the POMS comprised 34 items with the four subscales (1) Vigor, (2) Depression/Anxiety, (3) Fatigue, and (4) Hostility, all of which were scored on a 5-point Likert scale. In order to measure exercise-dependent changes in mood states, we followed a large body of literature (e.g., Berger & Motl, 2000) in using instructions from the POMS items asking respondents how they felt "right now, at this moment." Both the STAI and the POMS are scales with sound psychometric properties (Bullinger et al., 1990; Laux et al., 1981). Reliability measures in the current sample were adequate (Cronbach's α STAI ≥ .87; Cronbach's α POMS ≥ .84).

We assessed enjoyment of the exercise using the validated German version of the PACES (Jekauc et al., 2013). Since we aimed to measure exercise enjoyment, we modified the scale to a state measure with 18 items, beginning with "How do you rate the exercise you have been doing?" Respondents were able to rate items on a 5-point continuum: 1 = "I enjoyed it" to 5 = "I hated it." Scores on these items were recoded and then averaged; thus, higher average scores represent greater enjoyment of the exercise. The scale used in this study showed excellent internal consistency (Cronbach's α = .92).

Blood pressure. Prolonged decreases in resting blood pressure are a widely observed health-relevant phenomenon following acute exercise called post exercise hypotension (MacDonald, 2002). In line with previous research suggesting an onset of post exercise hypotension within the first 30 minutes after exercise (MacDonald, 2002), we measured systolic and diastolic blood pressure before and four times after the exercise (POST1, POST10, POST20, POST30) using an automatic sphygmomanometer (M300, Omron Healthcare Co., Kyoto, Japan). Measurements were taken on the left arm at heart level while the participant was seated in an upright position.

EEG recording and processing. Increased alpha activity is frequently observed following acute exercise (Crabbe & Dishman, 2004). Increased alpha activity is commonly interpreted as a decrease in cortical activation (Oakes et al., 2004; Shagass, 1972) and can be considered potentially health-relevant as it is associated with decreased anxiety and increased relaxation and well-being (e.g., van Boxtel et al., 2012). In line with previous research (Schneider et al., 2009), to measure alpha activity we recorded EEG activity with eyes closed for 5 min sessions prior to the exercise (PRE) and 2 min (POST2), 15 min (POST15), and again 30 min (POST30) after the exercise. EEG data from 30 electrodes on standardized scalp sites covering the entire scalp were collected by IMAGO (pfitec®, Endingen, Germany) by means of a 136-channel EEG system with active signal shielding technology (Refa_Ext-system, TMS International B.V., www.tmsi.com). EEG data was re-sampled to 256 Hz and re-referenced to average reference, and then a band-pass filter was applied (0.5–49 Hz; Notch at 50 Hz). After segmentation into 2-second epochs (10% overlapping), artifact-free 2-second EEG epochs were subjected to conventional spectral analyses. Due to potential functional differences between lower and upper alpha activity (Kubicki et al., 1979), analyses were conducted for both alpha-1 (7.5–10 Hz) and alpha-2 (10–12.5 Hz). After averaging the power spectra across all epochs, we exported the mean alpha-1 and alpha-2- powers (μV^2) for each electrode and participant. For statistical analyses, we calculated global and region-specific measures (frontal, temporal, central-parietal, occipital) on the basis of log-transformed alpha-1 and alpha-2 powers of the electrodes (see additional details in the Supplementary Material available online). On the basis of a meta-analysis indicating that exercise is also implicated in changes in other frequency bands (Crabbe & Dishman, 2004), we conducted further exploratory analyses with δ [0.5–3.5 Hz], θ [3.5–7.5 Hz], β_1 [12.5–18.5 Hz], and β_2 [18.5–35.0 Hz] frequency bands (for details, see online supplementary material).

Covariates. We assessed levels of exercise and daily activity using the validated Physical Activity, Exercise, and Sport Questionnaire (Fuchs et al., 2015). We assessed preference for cycling with a single-item measure asking participants, “How much do you like to cycle?” (Scale: 1 = *I like it a lot* to 5 = *I dislike it*). For further analyses and improved interpretability, this item was recoded. We assessed the amount of sleep and nicotine, caffeine, alcohol, and drug consumption using single-item measures asking participants about the respective amounts in the last 24 hours.

Statistical Analyses

In order to test for both the influence of habitual expectation (continuous variable) and induced expectation (grouping variable), we employed several hierarchical regression analyses. Similar to using a set of planned contrasts in an ANOVA context, linear multiple regression can be used to investigate research questions regarding specific group differences (Vickers, 2005). Furthermore, the use of hierarchical regression analyses has the advantage that for each dependent variable we were able to investigate in only one analysis both the effect of habitual expectations and that of induced expectations using planned orthogonal contrasts (Wendorf, 2004). For the resulting beta weights, we also report bias-corrected and accelerated 95 % bootstrap confidence intervals (95 % CI) based on 1,000 samples in Table 3 and 4. Selected effects of habitual expectations are displayed in Figure 2. Note that while habitual expectations were included as a continuous variable in all regression analyses, graphical illustrations of habitual expectation effects are based on median-split data for improved visualization. Note that we refrained from further correction of the significance level ($p < .05$) due to the use of several hierarchical regression analyses because of the highly dependent nature of tests (McDonald, 2014), particularly for the neurophysiological data. Hemispheric differences of neurophysiological data were not assessed in the analyses presented here, as preliminary analyses revealed that all effects were independent of the hemisphere (in line with previous research, despite a growing body of literature examining hemispheric asymmetry; Crabbe & Dishman, 2004). Additionally, for each of our regression analyses we conducted separate hierarchical regression analyses to control for variables known to specifically influence blood pressure and EEG measurements (time of day, amount of sleep, and nicotine, caffeine, alcohol, and drug consumption) and for several potential moderators influencing exercise-induced health effects, such as age, BMI, levels of exercise and daily activity, fitness, preference for cycling, and rate of perceived exertion (e.g., Hoffman & Hoffman, 2008; Rocheleau et al., 2004; Schneider et al., 2009). These analyses did not modify the reported pattern of results.

Table 1 shows descriptive statistics of study groups at baseline. Summary statistics and zero-order correlations of variables included in reported regression analyses are provided in the Supplementary Material available online (see Table S2). All statistical analyses (correlation analyses, paired t-tests, ANOVAs, and regression analyses) were conducted with SPSS Version 22. All tests were two-tailed with a level of significance of $p < .05$.

Results

Effects of acute exercise on psychological, physiological, and EEG measures

First, we aimed at replicating previous research by establishing that, regardless of group assignment, the short-term exercise modulated psychological, physiological, and EEG measures in the way described in the literature (Table 2). In short, on a psychological level participants reduced their state anxiety (STAI), depression/anxiety (POMS), and hostility (POMS), and on a descriptive level they increased their vigor (POMS) and reduced their fatigue (POMS) (both nonsignificant). On a physiological level, our results mirror what is known as post-exercise hypotension: Participants increased their systolic/diastolic blood pressure immediately after the exercise, but reduced these levels 10–30 minutes below baseline levels. On a neurophysiological level, participants increased their alpha-1 and alpha-2 power levels after exercising compared with before.

Hierarchical multiple regression analyses

In order to test our hypotheses regarding a potential moderating effect of habitual and induced expectations on acute exercise benefits, we calculated separate hierarchical regression analyses (one for each of the psychological, physiological, and EEG measures used in this study). In each regression model, we entered the respective baseline in Step 1, the continuous variable habitual expectation in Step 2, and, according to our hypotheses, a set of three planned orthogonal contrasts representing the grouping factor induced expectation in Step 3: (1) all conditions inducing positive expectations (*Enhanced Expectation*/*Expectation*) versus *Control 1*; (2) *Enhanced Expectation*/*Expectation* versus *Control 2*; and (3) *Enhanced Expectation* versus *Expectation*. This was performed for each contrast, with positive values for individuals with more positive expectation conditions. Thus, in each contrast more positive beta weights suggest a greater influence of expectations. Hereafter, we will refer to these comparisons as Contrast 1, Contrast 2, and Contrast 3. Furthermore, interaction terms for *habitual x induced expectations* were included in exploratory regression analyses. As none of these interaction terms explained additional variance, they were not included in the presented regression models.

Results from hierarchical regression analyses on the psychological level are shown in Table 3. Individuals with higher levels of habitual expectations were more likely to enjoy the acute exercise, reduce STAI anxiety more, and increase POMS vigor more. Figure 2a displays enjoyment data and Figure 2b-c graphical illustrations of anxiety and vigor effects, both based on median-split data for improved visualization. Participants' changes on the POMS subscales depression/anxiety and hostility were not predicted by habitual expectations. Although the reasons for these null findings are not entirely clear, it is possible that this is due to floor effects of the two subscales used (see also Table 1). In contrast to the habitual expectations, participants' induced expectations were unrelated to psychological exercise effects.

On a physiological level, participants' blood pressure changes following the exercise were independent of expectations, as they were unrelated to their habitual expectations (for POST10, diastolic blood pressure: *ß* = -.23, *p* = .170, 95 % CI [-.542, 021] with ΔR^2 = .051, *p* = .004; for all other blood pressure measures, $\Delta R^2 \leq .004$, $p \geq .356$) or induced exercise expectations, $\Delta R^2 \leq .030$, *p*s $\geq$ .113.

On a neurophysiological level, for alpha-1 and alpha-2 each we performed three separate hierarchical regression analyses predicting global alpha-1 and alpha-2 power (average from all electrodes) two minutes (POST2), 15 minutes (POST15), and 30 minutes following the exercise (POST30). As shown in Table 4, individuals with more positive habitual expectations were more likely to increase their global alpha-2 power at POST30 to a greater extent. Regarding induced expectations, unexpectedly, participants with induced positive expectation increased global alpha-2 power at POST30 only as much as participants without specific expectation induction (*Control 1* condition). However, participants with induced positive expectations increased their global alpha-2 power at POST30 more than participants with more neutral expectations (Contrast 2); similarly, participants with more positive expectations tended to increase global alpha-2 power at POST30 more than participants with less positive expectations (Contrast 3; for further details, see Table 4). These effects were specific to the third (POST30) EEG measurement following the exercise, as participants' increases in global alpha-2 power at the other measurements (POST2/POST15) were unrelated to their habitual or induced expectations, *p*s > .630. Furthermore, participants' habitual and induced expectations were specifically related to changes in alpha-2 power: Neither changes in alpha-1 (*p*s ≥ .193) nor those in any other frequency band (see Table S4 in online supplementary material) were related to expectations. In order to further specify the relation between participants' expectations and alpha power changes in more specific brain regions (frontal, temporal, central-parietal, occipital), we performed further hierarchical regression analyses. These analyses revealed that participants' habitual (see Figure 2d for median-split data) and induced expectations (see also Table 4) were predominantly related to POST30 changes in alpha-2 power in frontal brain regions.

Discussion

Summary of Findings

The main finding of this study is that participants with more positive habitual expectations consistently showed not only stronger psychological benefits (higher exercise enjoyment, mood improvement, and anxiety reduction) but also larger potentially health-relevant neurophysiological increases (POST30 frontal alpha-2 power) following the exercise. Similarly, participants with positive induced expectations showed greater neurophysiological changes but not more psychological exercise benefits than their counterparts with neutral induced expectations. On the physiological level, participants decreased their blood pressure following the exercise, but this was independent of their expectations (habitual and induced).

Psychological Findings

Regarding psychological parameters, our results showed that participants' exercise enjoyment, mood states (vigor), and anxiety were associated with their habitual expectations. More positive habitual expectations towards exercise benefits were related to greater psychological exercise benefits. These findings indicate that expectations reflecting previous experience and cultural beliefs may play an important role in acute exercise benefits. They extend previous literature by suggesting that not only mood benefits (O'Halloran et al., 2002) but also broader psychological exercise benefits regarding anxiety and enjoyment might be affected by habitual expectations. Concerning induced exercise expectations, unlike Helfer and colleagues (2015), the present study did not show that manipulated expectations influenced psychological benefits. These contradictory results might be explained by the short (10 minutes) and light exercise used in the Helfer study compared to the 30 min moderate exercise in the present study. In fact, Helfer and colleagues stress that an ambiguous experience such as a short and light exercise presumably can be more effectively influenced by expectation manipulations than a more aversive experience (such as a longer moderate exercise, see also Ekkekakis & Petruzzello, 1999).

Neurophysiological Findings

On a neurophysiological level, the results of the present study are in accordance with previous EEG studies linking acute exercise with changes in brain alpha power (e.g., Schneider et al., 2009), indicating an increase in alpha activation predominantly over the frontal region following the exercise. Regarding habitual and ad hoc induced expectations, our neurophysiological findings extend the existing literature in several ways. First, our results suggest that individuals' habitual expectations affect the extent of neurophysiological change following acute exercise. More positive habitual expectations towards exercise benefits were associated with stronger increases in frontal alpha-2 power 30 minutes following the exercise, predominantly in the prefrontal region. Second, in a similar manner our results suggest that induced expectations also affect the extent of neurophysiological changes following an acute exercise. Notably, participants in more positive expectation conditions demonstrated greater frontal alpha-2 increases 30 minutes after the exercise. However, participants with induced positive expectations benefited similarly to those without specific expectation induction (*Control 1* condition). This result might be explained by the nature of control conditions. While we aimed not to influence participants' expectations in the *Control 1* condition, we aimed to reduce their outcome expectations in the *Control 2* condition (in order to further eliminate the influence of pre-existing expectations). Thus, our discrepant result might be due to pre-existing positive expectations in participants from the *Control 1* condition. However, this is speculative, and therefore future research with more diverse samples is warranted. Finally, the neurophysiological regression analyses applied in this study suggest a high degree of specificity. Both types of expectations (habitual and induced) only predicted increases in the upper alpha band (alpha-2) measured 30 minutes after the exercise; no relation was found either for the lower alpha band (alpha-1) at POST30 or for any alpha band at 2 and 15 minutes after the exercise. This pattern of results might be explained by the observation of Schneider and colleagues (2009) that increases in alpha activity immediately following a cycling exercise are rather unspecific and potentially reflect a global physiological adaptation to exercise, whereas prolonged exercise-induced changes in alpha activity (e.g., after 30 minutes) are more specific and putatively mirror cognitive processes.

Physiological Findings

Participants in our study also demonstrated typical exercise-induced decreases in blood pressure that are potentially health-relevant (post-exercise hypotension; see (MacDonald, 2002). However, these physiological benefits were unrelated to habitual or induced expectations. In contrast to this finding, a previous study investigating chronic exercise instead of acute exercise showed that modifying individuals' expectations can affect exercise blood pressure benefits over several weeks (Crum & Langer, 2007). On the basis of our data, we suppose that expectations are unlikely to acutely influence post-exercise hypotension. Possibly, expectations contribute to a chronic reduction of blood pressure following regular exercise by way of an improved long-term integration of acute blood pressure benefits or enhanced chronic adaptation to regular exercise (Liu et al., 2012).

Summary and Limitations

In summary, the presented results support the assumption that acute exercise benefits are dependent on expectations not only on a psychological but also on a neurophysiological level. Only blood pressure benefits seem independent of expectations. What stands out in this study is the role of habitual expectations reflecting previous experience and beliefs, as they were consistently associated with psychological and neurophysiological changes. The results concerning ad hoc expectation inductions were less consistent and showed effects only on the neurophysiological level. A limitation of this study concerning this matter is our decision against a manipulation check. Nevertheless, given the positive findings of Helfer and colleagues (2015) for expectation manipulations in short and low-intensity exercise and our neurophysiological results, one may suspect that stronger manipulations of expectations could also affect psychological benefits of longer moderate sessions of health-relevant exercise. A further related limitation concerns the operationalization of intensity in this study. Because we used maximal power output relative to body weight to determine exercise intensity instead of a direct measure of aerobic/anaerobic metabolism at graded exercise intensities, we cannot rule out that exercise intensity levels of participants may have been underestimated and differed somewhat in certain cases. Furthermore, our correlative design with respect to habitual expectations is a limitation. Hence, questions of causality cannot be resolved. Nevertheless, by controlling for other known influencing factors, our results suggest that expectation is a variable that is conceptually distinct from other variables previously shown to influence exercise health effects. A final limiting aspect of our study is an increased probability of a false positive result due to the use of several hierarchical regression analyses without correction for multiple comparisons. However, given the consistent and specific pattern of our results, we believe that our findings are an intriguing addition to the growing literature supporting the self-fulfilling power of expectations.

Implications

The role of expectations for psychological and neurophysiological exercise benefits has important implications. By shedding light on potential neurophysiological consequences of expectations in health behavior, our research may be of interest for researchers in health-related fields. In a practical sense, our results stress the importance of expectations based on previous experience and beliefs. Individuals with unfavorable outcome expectations often may not adequately benefit from their exercise, which might in turn reduce their engagement in physical activity and impair their health.

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Compliance with Ethical Standards

Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

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Table 1

Descriptive statistics (mean ± SD) of the study groups at baseline

Variable	Enhanced Expectation (n = 18)	Expectation (n = 20)	Control 1 No Expectation (n = 19)	Control 2 No-Effect Expectation (n = 19)
Age (years)	22.00 ± 3.38	22.60 ± 2.70	21.58 ± 3.17	21.37 ± 2.22
Body Mass Index (kg/m^2)	21.91 ± 2.34	21.62 ± 2.80	22.14 ± 2.67	21.91 ± 2.88
Physical fitness (P_{max}/kg)	3.07 ± 0.62	3.35 ± 0.55	3.16 ± 0.64	3.17 ± 0.61
Preference for cycling (1 – Min/5 – Max)	3.33 ± 1.33	3.90 ± 1.17	3.79 ± 0.98	3.89 ± 1.10
Activities of daily life (min/week)	219.92 ± 154.26	456.40 ± 602.54	421.13 ± 830.50	248.26 ± 113.38
Physical exercise (min/week)	1.55 ± 6.58	9.77 ± 24.00	8.63 ± 16.87	4.53 ± 13.70
Habitual Expectation	32.39 ± 8.37	35.95 ± 4.48	35.63 ± 6.37	35.84 ± 7.41
Anxiety (STAI)	36.28 ± 7.61	33.65 ± 4.37	36.68 ± 8.54	39.16 ± 8.14
Vigor (POMS)	1.91 ± 0.68	2.01 ± 0.64	1.77 ± 0.74	1.79 ± 0.52
Depression/Anxiety (POMS)	0.32 ± 0.53	0.16 ± 0.20	0.34 ± 0.39	0.59 ± 0.78
Fatigue (POMS)**	0.58 ± 0.50	0.89 ± 0.71	1.40 ± 0.82	1.40 ± 0.89
Hostility (POMS)	0.29 ± 0.66	0.11 ± 0.18	0.29 ± 0.56	0.45 ± 0.61
Systolic blood pressure (mm Hg)	112.67 ± 13.43	110.50 ± 9.31	114.32 ± 12.46	113.26 ± 13.18
Diastolic blood pressure (mm Hg)	71.94 ± 8.00	67.85 ± 5.62	71.00 ± 9.12	69.79 ± 6.76
Global alpha-2 power (μV^2)	0.46 ± 0.31	0.44 ± 0.52	0.60 ± 0.44	0.31 ± 0.40

Note. STAI – State-Trait Anxiety Inventory; POMS – Profile of Mood States.

** $p < .01$.

Table 2

Effects of acute exercise on psychological, physiological, and EEG measures (N = 76)

			ANOVA results		
Measure	Before exercise	After exercise	Test statistics	p	$\eta^2_{partial}$
Anxiety (STAI)	36.41 ± 7.44	33.49 ± 6.57	$F(1, 75) = 24.18$	< .001	.24
Vigor (POMS)	1.87 ± 0.64	2.00 ± 0.87	$F(1, 75) = 2.52$	.117	.03
Depression/Anxiety (POMS)	0.35 ± 0.53	0.18 ± 0.39	$F(1, 75) = 31.92$	< .001	.30
Fatigue (POMS)	1.07 ± 0.81	0.98 ± 0.75	$F(1, 75) = 1.05$	.308	.01
Hostility (POMS)	0.29 ± 0.53	0.13 ± 0.37	$F(1, 75) = 14.13$	< .001	.16

		After exercise				ANOVA results		
Measure	Before exercise	POST1	POST10	POST20	POST30	Test statistics	p	$\eta^2_{partial}$
Systolic blood pressure (mm Hg)	112.66 ± 11.99	120.12 ± 11.30	109.96 ± 10.87	108.14 ± 10.57	108.38 ± 9.84	$F(3.324, 249.277) = 89.28$[1]	< .001	.54
Diastolic blood pressure (mm Hg)	70.09 ± 7.47	72.05 ± 7.53	70.04 ± 7.41	68.88 ± 6.48	69.72 ± 6.51	$F(4, 300) = 8.54$	< .001	.10

		After exercise			ANOVA results		
Measure	Before exercise	POST2	POST15	POST30	Test statistics	p	$\eta^2_{partial}$
Global alpha-1 power (µV²)	0.35 ± 0.40	0.48 ± 0.40	0.46 ± 0.41	0.44 ± 0.42	$F(2.617, 196.293) = 45.10$[1]	< .001	.38
Global alpha-2 power (µV²)	0.45 ± 0.43	0.57 ± 0.42	0.55 ± 0.43	0.53 ± 0.43	$F(2.622, 196.618) = 37.80$[1]	< .001	.34

Note. Data are presented as mean ± standard deviation. POST2 (as an example): measurement 2 min after exercise.

[1] Greenhouse-Geisser correction due to violation of sphericity.

Table 3

Summary of hierarchical regression analyses of habitual and induced exercise expectations predicting psychological exercise effects (N = 76)

Variable	PACES β	PACES 95 % CI[1]	STAI anxiety β	STAI anxiety 95 % CI	POMS vigor β	POMS vigor 95 % CI	POMS depression/anxiety β	POMS depression/anxiety 95 % CI	POMS fatigue β	POMS fatigue 95 % CI	POMS hostility β	POMS hostility 95 % CI
Step 1												
Baseline			.733**	[.543, .917]	.588**	[.412, .765]	.871**	[.599, 1.000]	.538**	[.316, .729]	.746*	[.316, 1.000]
Step 2												
Baseline			.715**	[.522, .891]	.538**	[.356, .709]	.874**	[.596, 1.000]	.542**	[.304, .737]	.750*	[.320, 1.000]
Habitual Expectation	.472**	[.239, .729]	-.202*	[-.347, -.005]	.213*	[.053, .369]	-.029	[-.153, .074]	-.172	[-.406, .030]	-.084	[-.255, .062]
Step 3												
Baseline	-		.700**	[.485, .874]	.539**	[.342, .737]	.892**	[.604, 1.000]	.497**	[.246, .686]	.785*	[.372, 1.000]
Habitual Expectation	.497**	[.260, .776]	-.203*	[-.352, .002]	.197*	[.023, .353]	-.003	[-.109, .094]	-.180	[-.426, .010]	-.041	[-.163, .066]
Induced Expectation C1	.049	[-.145, .244]	.051	[-.127, .229]	-.019	[-.213, .154]	-.022	[-.117, .076]	-.043	[-.256, .176]	.013	[-.110, .113]
Induced Expectation C2	.155	[-.075, .407]	-.072	[-.223, .056]	-.002	[-.183, .179]	.119	[.006, .222]	-.102	[-.288, .077]	.257†	[.098, .404]
Induced Expectation C3	.035	[-.170, .240]	.020	[-.138, .200]	-.077	[-.281, .092]	.096†	[.009, .181]	.025	[-.136, .183]	.106	[.001, .188]
Step 1. R^2	-		.538***		.346***		.759***		.290***		.556*	
Step 2. R^2	.222***		.578***		.389***		.760***		.319***		.564†	
Step 2. ΔR^2	.222***		.041*		.043*		.001		.030†		.007	
Step 2. Δ Cohen's f^2	0.29		0.09		0.07		0.00		0.04		0.02	
Step 3. R^2	.254***		.584***		.395***		.781***		.333***		.638	
Step 3. ΔR^2	.032		.005		.006		.021†		.014		.074**	
Step 3. Δ Cohen's f^2	0.04		0.01		0.01		0.10		0.02		0.20	

Note. Baseline represents the variable that corresponds to the respective outcome variable (e.g., POMS vigor). Induced Expectation C1: Contrast *Enhanced Expectation* / *Expectation* vs. *Control 1* (No Expectation); Induced Expectation C2: Contrast *Enhanced Expectation* / *Expectation* vs. *Control 2* (No-Effect Expectation); Induced Expectation C3: Contrast *Enhanced Expectation* vs. *Expectation*. Δ Cohen's f^2 represents the individual contribution of the additional predictor/set of predictors. According to Cohen (1988), effect sizes f^2 of 0.02, 0.15, and 0.35 are considered small, medium, and large, respectively.

[1] Bias corrected and accelerated bootstrap 95% CIs (1000 samples) are reported in square brackets.

† *p* < .10. * *p* < .05. ** *p* < .01.*** *p* < .001.

Table 4

Summary of hierarchical regression analyses of habitual and induced exercise expectations predicting neuronal exercise effects (increase in POST30 alpha-2; N = 76)

	Global alpha-2		Frontal alpha-2		Temporal alpha-2		Central-parietal alpha-2		Occipital alpha-2	
Variable	β	95 % CI[1]	β	95 % CI	β	95 % CI	β	95 % CI	β	95 % CI
Step 1										
Baseline	.963**	[.912, 1.000]	.951**	[.891, 1.000]	.918**	[.826, 1.000]	.965**	[.908, 1.000]	.975**	[.929, 1.000]
Step 2										
Baseline	.955**	[.902, 1.000]	.941**	[.879, 1.000]	.900**	[.810, .992]	.959**	[.899, 1.000]	.973**	[.925, 1.000]
Habitual Expectation	.067*	[.005, .126]	.086*	[.009, .156]	.089*	[.012, .176]	.059*	[.001, .115]	.019	[-.044, .072]
Step 3										
Baseline	.943**	[.882, 1.000]	.926**	[.858, .995]	.891**	[.793, .984]	.947**	[.889, 1.000]	.970**	[.918, 1.000]
Habitual Expectation	.086**	[.022, .144]	.109**	[.025, .181]	.100*	[.024, .198]	.076**	[.012, .137]	.033	[-.028, .085]
Induced Expectation C1	.006	[-.059, .066]	-.012	[-.088, .065]	.021	[-.096, .122]	.011	[-.062, .076]	.026	[-.020, .077]
Induced Expectation C2	.073*	[.014, .131]	.093**	[.030, .158]	.074	[-.019, .178]	.062*	[.002, .118]	.053	[-.013, .113]
Induced Expectation C3	.056†	[-.001, .120]	.075*	[.010, .142]	.002	[-.075, .072]	.050	[-.009, .107]	.037	[-.008, .091]
Step 1. R^2	.928***		.905***		.843***		.932***		.951***	
Step 2. R^2	.932***		.912***		.851***		.936***		.951***	
Step 2. ΔR^2	.004*		.007*		.008†		.003†		.000	
Step 2. Δ Cohen's f^2	0.06		0.08		0.05		0.06		0.00	
Step 3. R^2	.941***		.925***		.858***		.942***		.956***	
Step 3. ΔR^2	.008*		.013*		.007		.006†		.005*	
Step 3. Δ Cohen's f^2	0.15		0.17		0.05		0.10		0.11	

Note. Baseline represents the variable that corresponds to the respective outcome variable (e.g., Frontal alpha-2). Induced Expectation C1: Contrast *Enhanced Expectation* / *Expectation* vs. *Control 1* (No Expectation); Induced Expectation C2: Contrast *Enhanced Expectation* / *Expectation* vs. *Control 2* (No-Effect Expectation); Induced Expectation C3: Contrast *Enhanced Expectation* vs. *Expectation.* Δ Cohen's f^2 represents the individual contribution of the additional predictor/set of predictors. According to Cohen (1988), effect sizes f^2 of 0.02, 0.15, and 0.35 are considered small, medium, and large, respectively.

[1] Bias corrected and accelerated bootstrap 95% CIs (1000 samples) are reported in square brackets.

† $p < .10$. * $p < .05$. ** $p < .01$.*** $p < .001$.

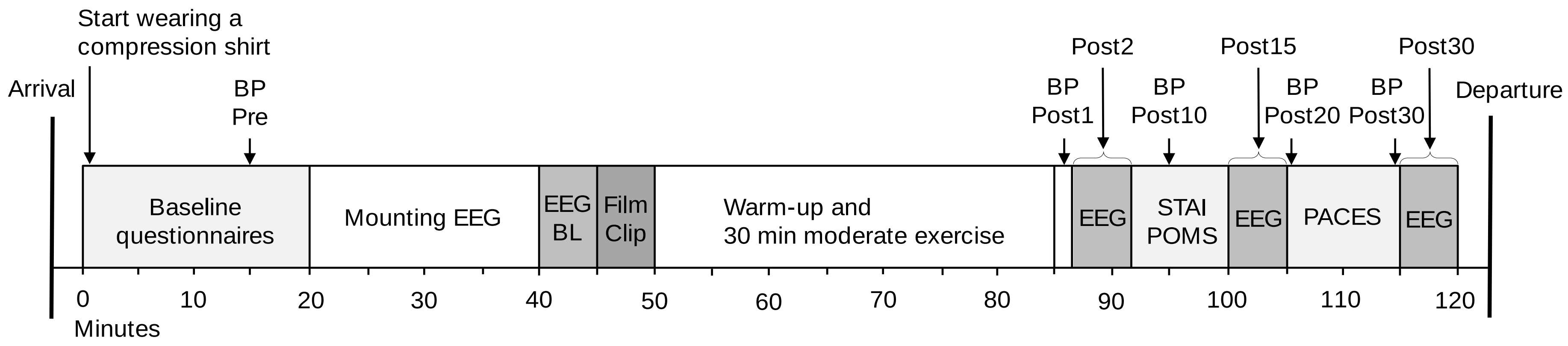

Fig. 1. Experimental protocol. EEG BL = Electroencephalography baseline measurement; STAI = State-Trait Anxiety Inventory; POMS = Profile of Mood States; PACES = Physical Activity Enjoyment Scale; BP Pre = Blood Pressure baseline measurement; BP Post 10 = Blood Pressure measurement 10 minutes after exercise completion.

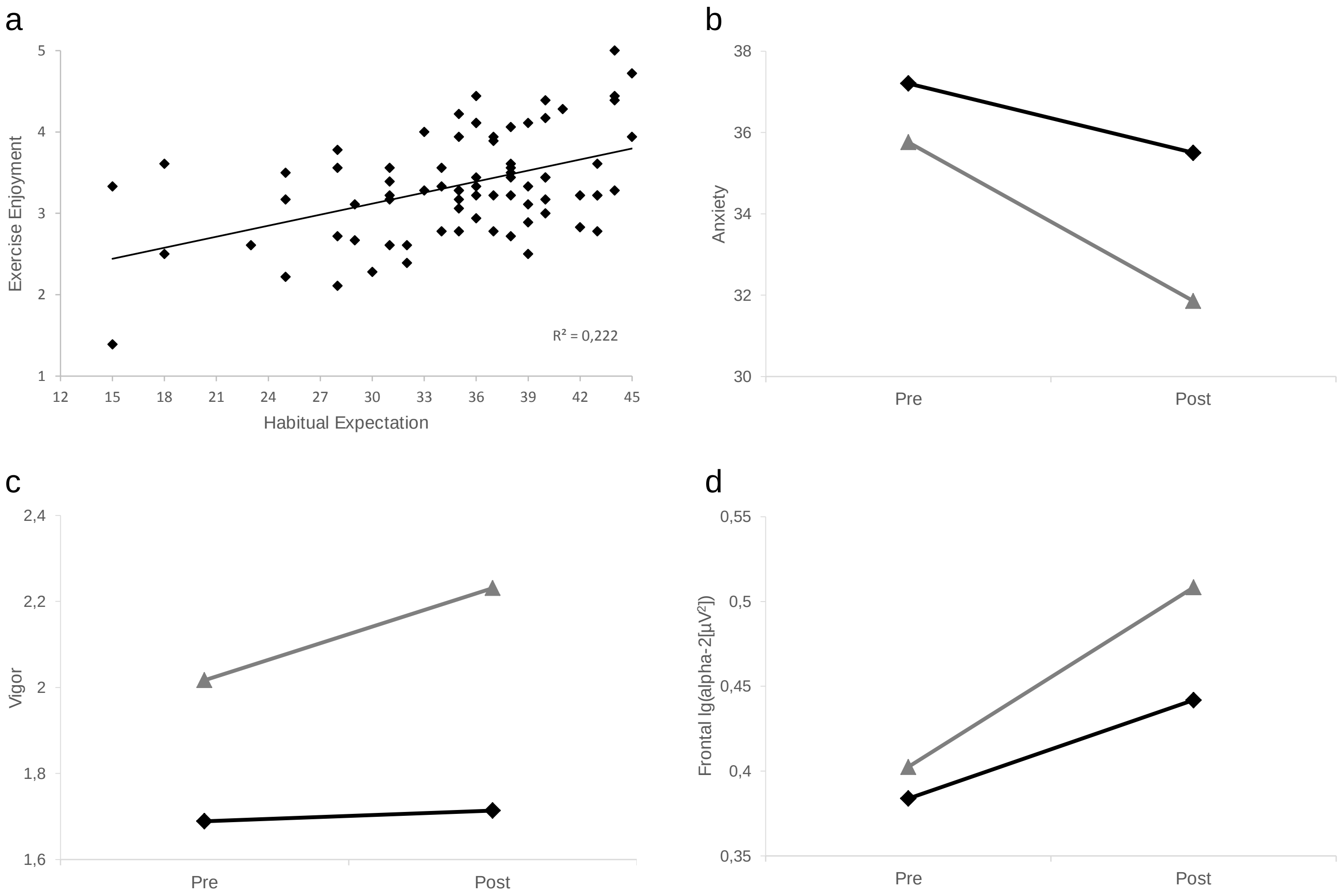

Fig. 2. Exercise enjoyment as a function of habitual expectations (a). Changes in anxiety (b), vigor (c), and frontal alpha-2 power (d) over time as a function of habitual expectation (for improved graphical illustration based on median splitted data). Dark gray lines with diamond points represent participants with low habitual outcome expectations. Light gray lines with triangle points represent participants with high habitual outcome expectations.