Incidental affective responses to physical effort: a virtual reality study

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Abstract

The role of affective responses to effort in the regulation of physical activity behavior is widely accepted. Yet, to investigate these affective responses during physical activity, most studies used direct self-reported measures that are prone to biases (e.g., social desirability, ability to introspect). Here, to reduce these biases, we used an indirect self-reported measure (i.e., an affect misattribution procedure) to assess the incidental affective response to effort elicited during a physically active performance in 42 healthy young adults. Specifically, participants rated the pleasantness of neutral human faces presented on a virtual environment while cycling at different levels of physical effort. We used this rating as an indicator of the incidental affective response to effort. Results showed that higher perceived effort was associated with lower pleasantness ratings of neutral faces, with this effect only emerging at moderate-to-high levels of perceived effort. Further analyses showed that higher actual effort was also associated with lower pleasantness ratings of neutral faces. Overall, these findings suggest that higher levels of perceived effort are associated with decreased affective responses during physical activity. These results also provide evidence on the feasibility of capturing affective responses during physical activity without relying on direct self-reported measures.

Keywords: exercise, emotion, automatic, virtual reality, physical exertion.

Introduction

Exercise is one of the most popular New Year's resolutions. Unfortunately, this resolution often fails by February (Luciani, 2015). Understanding the gap between intention to be physically active and engagement in an active lifestyle could be key to reduce high levels of physical inactivity worldwide (Boisgontier & Iversen, 2020; Kohl et al., 2012). Meanwhile, every six seconds, someone dies from causes associated with physical inactivity, for a total of 5.3 million deaths each year (WHO, 2020). Recent literature suggests that affective mechanisms are essential in explaining this inability to translate intention to be physically active into action (Brand & Ekkekakis, 2018; Cheval et al., 2018; Conroy & Berry, 2017). In this study, we extended this line of research by investigating the incidental affective responses elicited by effort during physical activity.

Affective evaluations and physical activity

Several theories suggest that affective evaluations of the concept of physical activity are instrumental in regulating physical activity behavior (Brand & Ekkekakis, 2018; Cheval et al., 2018; Conroy & Berry, 2017). These theories are supported by experimental studies showing that direct self-reported affective evaluations of physical activity is predictive of physical activity (Rhodes et al., 2009; Williams & Bohlen, 2019). Moreover, studies based on eye-tracking or computerized reaction-time measures, such as the Implicit Association Test (IAT; Greenwald et al., 1998), the dot probe task (Pool et al., 2016), or the manikin task (Krieglmeyer & Deutsch, 2010), showed that cues related to physical activity elicit positive automatic affective evaluations (Bluemke et al., 2010; Chevance et al., 2017; Conroy et al., 2010; Rebar et al., 2015) and behavioral approach tendencies (Cheval et al., 2015; Cheval et al., 2014), especially in the most physically active individuals (Cheval, Miller, et al., 2020). In turn, these affective evaluations are thought to influence physical activity engagement (Conroy & Berry, 2017). In sum, these findings suggest that affective evaluations are critical in explaining engagement in physical activity, with individuals exhibiting more negative affective evaluations being at higher risk of physical inactivity.

How are affective evaluations of physical activity built?

At the conceptual level, affective evaluations are thought to be gradually learned through the repetition of positive (e.g., pleasure) or negative (e.g., displeasure) affective responses felt during physical activity (Brand & Ekkekakis, 2018; Cheval & Boisgontier, 2021; Cheval et al., 2018; Conroy & Berry, 2017). The repetition of positive affective responses during physical activity promotes the development of positive affective evaluations stored in memory, while the repetition of negative affective responses during physical activity favors the development of negative evaluations. As a result of these well-learned affective associations between affective responses and physical activity, the affective evaluations may well be activated even when people are only exposed to physical activity cues (Brand & Ekkekakis, 2018; Cheval & Boisgontier, 2021; Cheval et al., 2018; Conroy & Berry, 2017), and prevent (vs. favor) them from actually being physically active despite intentions to be active. Therefore, affective responses elicited during physical activity may contribute to building the affective evaluations of physical activity.

How to measure affective responses during physical activity?

To examine the affective responses elicited during physical activity most studies have focused on physical effort, a feature that is consubstantial to physical activity (Maltagliati et al., submitted). To investigate the associations between effort and affective responses, these studies have mainly relied on direct self-reported measures, such as the Feeling Scale (Hardy &

Rejeski, 1989), the Felt Arousal Scale (Svebak & Murgatroyd, 1985) or the Empirical Valence Scale (Lishner et al., 2008). Results have consistently shown that affective responses and physical effort levels are strongly intertwined: most individuals report more negative affective responses (e.g., increased displeasure) when physical effort increases (Ekkekakis et al., 2011). This finding is consistent with the theory of effort minimization in physical activity (TEMPA; Cheval & Boisgontier, 2021), which argues that physical effort is, in most cases, perceived as an aversive experience that needs to be minimized or avoided.

Although they provide useful knowledge, direct self-reported measures have limitations that can lead to inaccuracies in the measurement of affects experienced during physical activity. First, participants' reported affective responses to effort during physical activity may be distorted by normative responses, social pressure, and social desirability (Ekkekakis et al., 2018). For example, individuals may rate their affective responses to effort more positively to create a socially desirable impression (Lane, 2008). Second, self-reports require one to evaluate their own mental and emotional processes (i.e., introspection). However, some individuals are more able to introspect than others (Lane et al., 1990; Lichev et al., 2015). Accordingly, rather than purely reflecting affects per se, direct self-reported measures likely also reflect an ability to introspect and to resist social pressure and desirability.

The present study

To address the limitations associated with direct self-reports, we created a paradigm based on an indirect measure of affective responses to effort during an immersive whole-body exercise task on a cycloergometer. Specifically, participants rated the pleasantness of human faces projected in a virtual environment while cycling at different effort intensities. Consistent with the affect-as-information hypothesis, suggesting that affects operate as a source of information that influence judgement, we used this rating as an indicator of the incidental affective response to effort (Clore et al., 2001). The rationale of this task is similar to the one suggested by the affect misattribution procedure (AMP; Payne et al., 2005; Payne & Lundberg, 2014). In this procedure, primes (e.g., positively and negatively-valenced images) are briefly presented before neutral pictograms (e.g., Chinese pictographs) and participants are asked to judge the pleasantness of the pictograms. The affective responses automatically elicited by the prime are expected to impact responses unbeknownst to the participants. Specifically, positive and negative primes are expected to favor a positive or negative evaluation of the neutral pictograms, respectively. The design of our study is inspired by this design, with the conditions "positive and negative primes" being replaced by "different levels of physical effort", and with the "neutral pictographs" being replaced by "neutral faces". Based on previous literature (Cheval & Boisgontier, 2021; Ekkekakis et al., 2011), we hypothesized that higher levels of perceived effort would be associated with decreased incidental affective responses, as measured by decreased pleasantness ratings of the neutral faces. Results supporting this hypothesis would suggest that changes in incidental affective responses as a function of perceived physical effort can be captured without relying on direct self-reported measures.

Methods

Study preregistration can be found at https://aspredicted.org/JYD_GBF. Data, code, and other material can be found at https://doi.org/10.5281/zenodo.6405782

Participants

The sample size required for 90% power was estimated using the simr package in R (Green & MacLeod, 2016), which was developed to calculate power for generalized linear mixed models based on Monte Carlo simulations. Details about this sample size estimate are available in the study's pre-registration (https://doi.org/10.5281/zenodo.6405782). The results of the Monte Carlo simulation of the mixed model based on the predicted model (see Statistical Analysis) led to a minimum sample of N = 29 participants. We therefore planned to recruit at least 40 participants to account for data loss.

Recruitment was done through flyers distributed on the University of Geneva campus and in other places in Geneva. Participants interested in the study were asked to contact the research assistants by email or telephone. They did not receive any compensation for their participation in the study. In addition, participants were also recruited via the University of Geneva's SONA participants recruitment system and were offered course credit for their participation. Participants fulfilling the following inclusion criteria were eligible for the study: 18 years of age or older, free of any medical conditions that would prohibit physical activity without supervision, and able to provide written informed consent. The exclusion criteria were an inability to follow the procedure, insufficient knowledge of French, or taking psychotropic medication or illicit drugs at the time of the study. A total of 57 participants were recruited, but 15 participants' data were removed from analyses due to participants not completing the physical activity task because of a problem with data collection or experiencing nausea during the virtual reality task. Thus, the final sample was composed of 42 participants.

Apparatus

Cycling task in an immersive virtual reality environment. A whole-body virtual reality environment in which participants can exercise on a cycloergometer was developed using Unity technologies (Unity 3D 2021.2). A resistance (Tacx® Boost Bundle; Garmin) was added to the rear wheel of a static bike to experimentally manipulate physical effort (Figure 1). The virtual environment was delivered via a virtual-reality headset (HTC Vive Pro Eye). This headset has a resolution of 1440x1600 pixels per eye, a refresh rate of 90Hz, and a field of view of 110°. The lighthouse-based HMD tracking was replaced with an Optitrack optical motion capture system (Prime 13 camera, 240 fps frame rate) as this is the system used to acquire bike wheel speed and handlebar orientation. A pilot study was conducted (n = 5) to test the feasibility of the task. To increase ecological validity, we used different types of ground (e.g., floor, grass). A video of the cycling task is available at https://doi.org/10.5281/zenodo.6405782.

Stimuli. The FACSGen facial action coding system (Krumhuber et al., 2012, 2012) was used to create realistic 3D facial expressions on avatar faces. Studies showed that the FACSGen tool generates experimentally manipulated synthetic avatar emotions that are easily identifiable by naïve observers (Mumenthaler & Sander, 2012, 2015; Scherer et al., 2018). Here, we used a sample of 70 validated faces[1] (35 men and 35 women) from the Geneva Faces And Voices database (GEFAV; Ferdenzi et al., 2015). These 70 faces displayed a negative (i.e., anger), positive (happiness), or neutral expression, for a total of 210 stimuli.

Procedure

Participants completed a 1-h session that started with written informed consent to participate in the study approved by the Ethics Committee of Geneva Canton, Switzerland (CCER-2019-00065). Next, participants completed a questionnaire assessing demographics and potential confounding variables (i.e., thirst, hunger, recent physical activity, sleep pattern, caffeine, alcohol, and cigarette consumption, potential health problems, visual acuity, desire for exercise

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[1] The faces from the GEFAV database were: 104, 106, 107, 109, 116-118, 123, 124, 131, 132, 147, 154, 160, 169, 177, 183, 190, 198, 204, 207, 244, 261, 280, 293, 302, 305, 306, 312, 313, 316, 323, 325, 329, 330, 336, 339, 344, 345, 346, 364, 366, 372, 373, 382, 387-389, 392, 395, 397, 398, 401, 405, 408-410, 413, 418, 422-425, 427, 437, 438, 440, 448, 450.

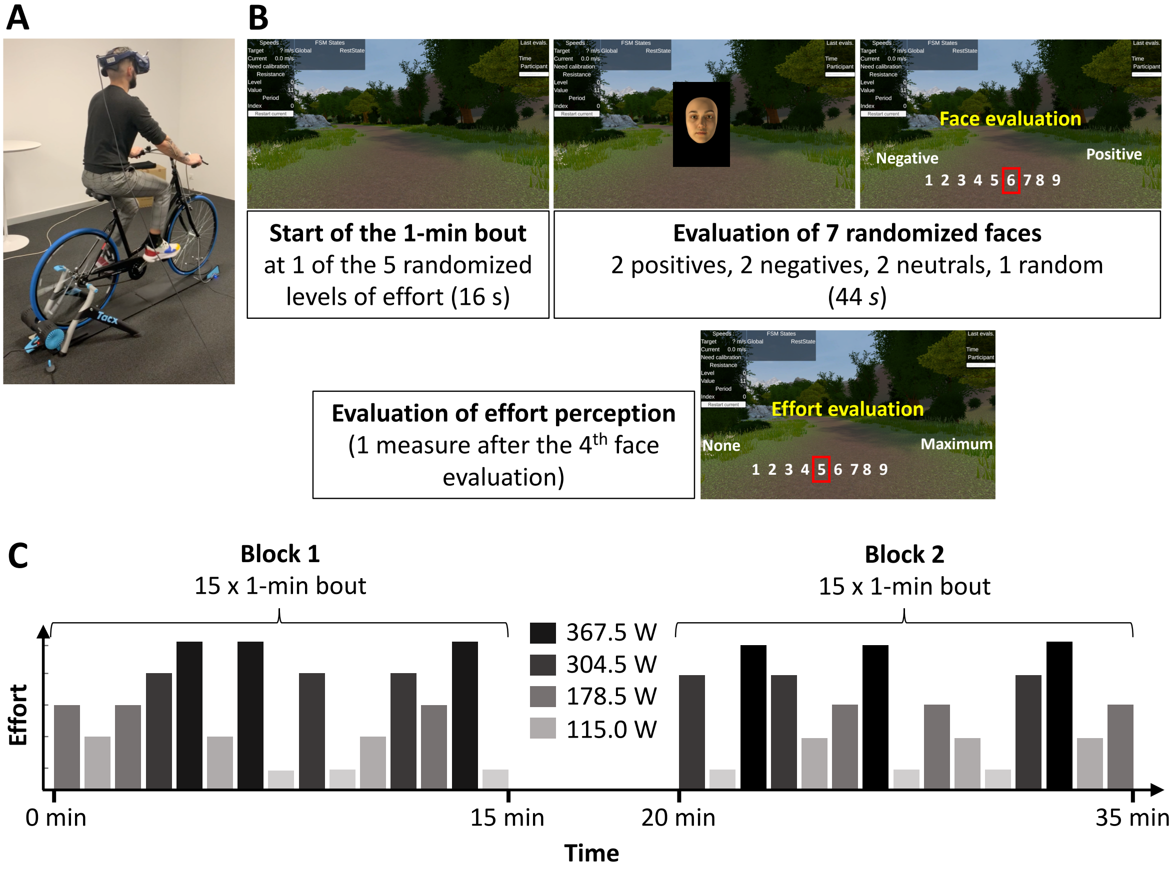
and rest, usual physical activity, motivation to be physically active, and exercise addiction). Then, participants sat on the bike and a virtual reality headset was positioned on their head by the experimenter under the supervision of a virtual reality engineer. Participants familiarized themselves with the virtual environment by pedaling at a self-selected speed for 30 sec. Next, the participants were asked to rate the faces while cycling at the different levels of physical effort. After the cycling task, a questionnaire was used to assess previous cycling and virtual reality experience, as well as the specific virtual reality experience of the current study (i.e., fatigue, boredom, comfort, ease, agreeability, nausea, and perceived immersion assessed with the Immersive Experience Questionnaire (IEQ; Jennett et al., 2008)).

Measures

Affect Misattribution Procedure. Participants performed a modified version of the affect misattribution procedure to assess incidental affective responses to effort elicited during a physically active performance. Participants were asked to rate the pleasantness of faces displayed on the virtual environment while cycling at five levels of physical effort: very easy (115.5 W), easy (178.5 W), moderate (241.5 W), hard (304.5 W), very hard (367.5 W). Each level of physical effort was repeated six times. In total, participants completed two 15-min blocks of fifteen 1-min cycling bouts, with a 5-min break in between blocks, for a total duration of about 35 min. During the first 16 s of each 1-min bout, the participants could adjust their cycling pace to the required effort. During the last 44 s, participants used the left and right handlebar buttons to rate 7 different faces on a Likert scale ranging from 1 “not at all pleasant” to 9 “extremely pleasant” that appeared below the face (Figure 1). The faces were presented for a duration of 2 s, and there was a 2-s delay between the affective response to effort and the presentation of the next face.

Overall, participants had to evaluate two times 21 different faces that were presented under the five levels of physical effort, leading to a total of 210 trials. These 21 faces (7 neutral; 7 negative, and 7 positive) were randomly selected from the 210 FACSGen faces. The faces were randomized across the two blocks, but we ensured that each emotional valence was presented at least twice in each 1-min bout of cycling (i.e., 2 neutral, 2 positive, 2 negative, and 1 random face). The pleasantness of the neutral faces was used as the primary outcome. The negative and positive faces were used in additional analyses.

Figure 1. Evaluative task and procedure. A. evaluative task. Participants were instructed to rate the pleasantness of faces displayed in the virtual environment while cycling at different intensities. **B. Procedure**. Participants were asked to complete 15 1-min cycling bouts at different effort intensity. The order of the effort intensity and of the projection of the faces were randomized for each participant. The total duration of the task was ~35-min, split into two blocks.



Perceived effort. Perceived effort was assessed using a Likert scale ranging from 1 “no particular effort to invest” to 9 “maximum effort to invest”. This measure was systematically assessed after the fourth face was evaluated. The perceived effort was used as the main predictor in the statistical analyses. Additional analyses were computed to examine the effect of actual effort.

Covariates. The following covariates were included in the model: block (1 vs. 2), bout (1 to 15), age, body mass index, and sex.

Statistical analysis

Participants’ actions and responses were recorded using the underlying C# language and the Unity application. Data included participant’s identification code, block index (1 to 2), bout index (1 to 15), trial index within bout (1 to 6), actual effort (1 to 5), perceived effort (1 to 9), the code of the face (see footnote 1), the gender of the avatar’s face (woman, man), the valence of the avatar’s face (neutral, positive, negative), and the rating of the pleasantness of the avatar’s face (1 to 9).

Incidental affective responses to effort during the physically active performance were assessed using the pleasantness ratings of the neutral faces, and were analyzed using linear mixed models. Mixed models allow for correct parameter estimation when data contains multiple cross-random effects, as in the current study where participants are crossed with stimuli (i.e., faces). In these conditions, mixed models have been found to decrease the risk of type-I error compared to traditional ANOVA (Boisgontier & Cheval, 2016). The linear mixed models included linear and quadratic effects of perceived effort as fixed factors. The quadratic effect was included to account for potential non-linear effects of perceived effort on the evaluation of neutral faces. A significant quadratic effect would indicate that the effect of perceived effort on incidental affective responses to effort was not constant across the perceived effort range (i.e., 1 to 9). For example, as observed for direct self-reports affective responses, the negative association between perceived effort and affective responses may only appear when effort intensity reaches a threshold (Ekkekakis et al., 2011). If the quadratic effect of perceived effort was significant, simple slopes, region of significance, and confidence bands were examined using computational tools for probing interactions in mixed models (Preacher et al., 2006). Models were adjusted for the abovementionned covariates (i.e., block, bout, age, body mass index, sex). All these variables were centered to allow for correct interpretation of the model intercept. Participants and stimuli (i.e., faces) were specified as random factors and included a random slope for the perceived effort at the level of participants. This random effect allowed the effect of perceived effort on pleasantness to vary across participants.

To reduce convergence issues, each model was optimized using the default BOBYQA optimizer (Powell, 2009), the Nelder-Mead optimizer (Nelder & Mead, 1965), the nlimb optimizer from the optimx package (Nash & Varadhan, 2011), and the L-BFGS-B optimizer (see Cheval et al., 2021; Cheval, Daou, et al., 2020; Frossard & Renaud, 2019, for similar procedure). Estimates of the effect size were reported using the conditional and marginal pseudo R^2 from the MuMin package (Barton, 2018). *P* values for the global effect of perceived effort were provided using likelihood ratio tests, in which we compared models with and without perceived effort as a fixed or random factor. Statistical assumptions associated with linear mixed models (i.e., normality of the residuals, linearity, multicollinearity, and undue influence) were met. The analyses were conducted in R with the lme4 and lmerTest packages (Bates et al., 2014; Kuznetsova et al., 2015; R Core Team, 2017).

Additional analyses

Three additional analyses were conducted. First, perceived effort was replaced with actual effort level (i.e., the five conditions of physical effort) as the main predictor. Second, the pleasantness of the neutral faces was replaced with the pleasantness of the positive faces as the outcome. Third, the pleasantness of the neutral faces was replaced with the pleasantness of the negative faces as the outcome. The purpose of the latter two additional analyses was to determine whether the effects were specific to neutral faces or whether they could be extended to emotionally-valenced stimuli.

Sensitivity analysis

In a sensitivity analysis, participants who felt nauseous during the task under virtual reality (i.e., > 5 on a scale ranging from 1 “no nausea at all” to 7 “a lot of nausea”), but who still completed the experimental procedure, were excluded because nausea can have a confounding influence on the incidental affective rating of the faces.

Results

Descriptive results

Table 1 shows the characteristics of the participants. The final sample included 42 participants (29 women; age = 27.2 ± 9.3 years; body mass index = 22.45 ± 3.45 kg.m^{-2}). On average, neutral, positive, and negative faces were respectively rated at 4.87 (± 0.50), 6.55 (± 0.61), and 2.89 (± 0.62) out of nine. These ratings confirm that participants were able to accurately determine the expression of the avatars' faces. Moreover, the perceived effort increased when the actual level of effort increased. Specifically, perceived effort was rated at 3.92 (± 1.64), 4.71 (± 1.43), 5.53 (± 1.36), 5.87 (± 1.43), 6.32 (± 1.41) out of nine for the very easy, easy, moderate, hard, and very hard effort condition, respectively. This result confirms that the effort manipulation was effective in changing the perception of effort during the task.

Table 1. Descriptive statistics

N = 42	Mean	SD
Age (years)	27.2	9.3
Gender (number; %)		
Women	29	69%
Men	13	31%
Body Mass Index	22.45	3.45
Evaluation of the pleasantness of faces (Likert scale; 1-9)		
Negative (anger) faces	2.89	0.62
Neutral faces	4.87	0.50
Positive (happiness) faces	6.55	0.61
Perceived effort (Likert scale; 1-9)		
Averaged over the exercise task	5.27	1.21
By actual levels of effort		
Very easy (115 W)	3.92	1.64
Easy (178.5 W)	4.71	1.43
Medium (241.5 W	5.53	1.36
Hard (304.5 W)	5.87	1.43
Very hard (367.5 W)	6.32	1.41

Notes. SD = standard deviation; W = watts.

Perceived effort and incidental affective responses

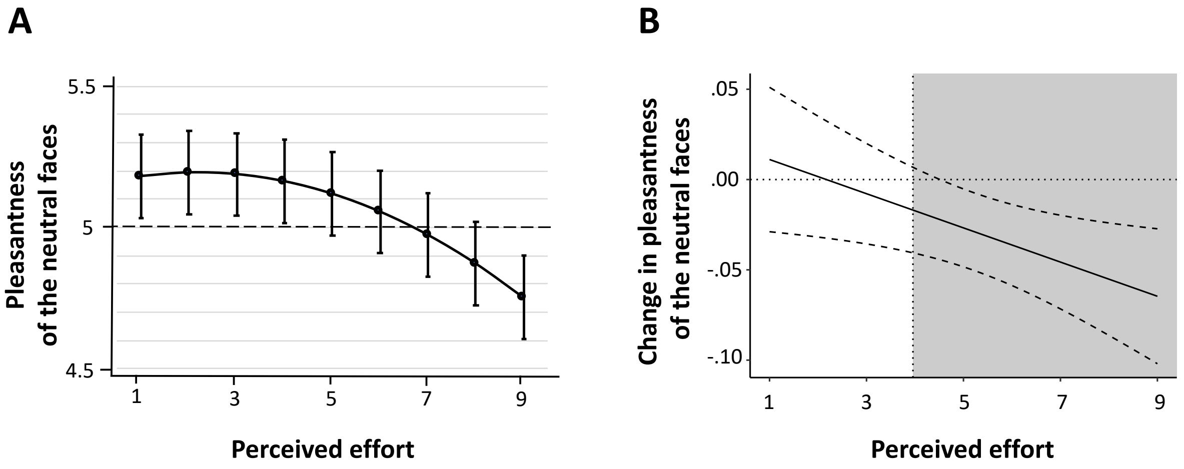
Perceived effort was associated with the pleasantness of neutral faces (*p* for global effect = 0.005; Figure 2A). Both the linear (b = -0.027, 95%CI = -0.048 – -.005, *p* = .020) and quadratic effect (b = -0.009, 95%CI = -0.017 – -0.001, *p* = .022) of perceived effort on pleasantness of neutral faces were significant (Table 2). The region of significance of the simple slope revealed that the negative effect of perceived effort on pleasantness of neutral faces had its lower bound estimated at 4.5 on the scale of effort ranging from 1 to 9 (Figure 2B). Since the scale had a one-unit interval, this result suggested that an increase in perceived effort was not significantly associated with a change in the evaluation of neutral faces when the level of perceived effort was < 5. However, this association was significantly negative when the level of perceived effort was ≥ 5. For example, when perceived effort was low (e.g., equal to 2), an increase in perceived effort was not significantly associated with a change in perceived pleasantness of neutral faces (b = 0.024, 95%CI = -0.025 – 0.076, *p* = .332). Conversely, when perceived effort was high (e.g., equal to 8), an increase in perceived effort was associated with a decreased pleasantness of neutral faces (b = -0.089, 95%CI = -0.144 – -0.033, *p* = .002). The other effects were not significant, though women tended to evaluate neutral faces less positively than men (b = -0.322, 95%CI= -0.658 – -0.014, *p* = .068). The variables included in the model explained 3.1% (fixed effects) and 38.8% (fixed + random effects) of the variance in pleasantness of neutral faces.

Table 2. Results of the mixed models predicting the evaluation of the pleasantness of neutral faces as a function of the perceived level of effort

Pleasantness of the neutral faces		
N = 42	b (95CI)	*p*
Fixed Effects		
Intercept	5.118 (4.832;5.405)	<.001
Perceived effort		
Linear effect	-0.027 (-0.048; -0.005)	.020
Quadratic effect	-0.009 (-0.017; -0.001)	.022
Covariates		
Age	-0.003 (-0.020;0.014)	.723
Sex (ref. men)		
Women	-0.322 (-0.658;0.014)	.068
Body mass index	-0.029 (-0.012;0.070)	.177
Block (ref. Block 1)		
Block 2	-0.032 (-0.027;0.091)	.284
Bout (1-15)	0.005 (-0.002;0.012)	.149
Random Effects		
Participants		
Intercept	0.213	
Perceived effort	<0.001	
Corr. (Intercept, Perceived effort)	-0.38	
Stimuli (Faces)		
Intercept	0.112	
Residual	0.590	
R^2	Marginal = .034; Conditional = .378	

Notes. 95CI = confidence intervals at 95%.

Figure 2. Results of the linear mixed models. A. Prediction of the pleasantness of neutral faces as a function of perceived effort. B. Region of significance of the effect of perceived effort on pleasantness of neutral faces as a function of the level of perceived effort.



Notes. A. Errors bars = standard errors. Dashed line = neutral evaluation of the neutral face (i.e., 5 on the scale ranging from 1 to 9). Above the dashed line, pleasantness is positively biased. Below the dashed line, pleasantness is negatively biased. B. A negative effect indicates that an increase in perceived effort was associated with a decreased rating of the neutral faces; solid line = mean; dashed line = 95% confidence interval; grey area = region of significance ($p < .005$).

Additional analyses

Actual physical effort. Results showed that an increase in actual effort was associated with a decrease in pleasantness of neutral faces (b = -0.020, 95%CI = -0.048 – -0.005, $p = .049$) (Table S1, Figure S1). The quadratic effect was not significant (b = 0.002, 95%CI = -0.015 – 0.019, $p = .808$), suggesting that the magnitude of the effect of actual effort on pleasantness of neutral faces was similar across the 5 levels of actual effort. Overall, results were consistent with those observed for perceived effort – higher levels of actual effort were associated with lower ratings of neutral faces.

Positive faces. Results showed no evidence of an effect of perceived effort on pleasantness of positive faces (b = -0.025, 95%CI = -0.051 – 0.001, $p = .072$) (Table S2, Figure S2).

Negative faces. Results showed no evidence of an effect of perceived effort on pleasantness of negative faces ($p = .785$ for the linear effect; $p = .618$ for the quadratic effect) (Table S3, Figure S2).

Sensitivity analysis

Results of the sensitivity analysis excluding participants who had nausea during the experiment (N = 6) were consistent with the results of the main analysis (Table S4, Figure S3). Specifically, both the linear (b = -0.032, 95%CI = -0.054 – -0.009, $p = .008$) and quadratic effect (b = -0.009, 95%CI = -0.018 – -0.001, $p = .030$) of perceived effort on pleasantness of neutral faces were significant. The region of significance of the simple slope revealed that the negative effect of perceived effort on pleasantness of neutral faces had its lower bound estimated at 4.9 on the nine-point scale of perceived effort.

Discussion

Main findings

Affective responses to physical effort have been recently considered essential for understanding the regulation of physical activity. However, these affective responses have mainly been investigated using direct self-reports, which are subject to reporting biases (e.g., social desirability, ability to introspect). In the current study, participants performed a cycling task under virtual reality while rating the pleasantness of neutral faces displayed in the virtual environment (i.e., an indirect self-reported measure) to capture incidental affective responses to physical effort. Consistent with our hypothesis, we found that higher perceived effort was associated with lower pleasantness of neutral faces, with this effect only emerging at moderate-to-high levels of perceived effort. Hence, our findings suggest that indirect self-reported measures can be used to capture incidental affective responses to effort during a physically active performance.

Comparison with other studies

Our results showing that the incidental positive affective response only decreased at moderate-to-high perceived physical effort supports previous literature (Ekkekakis et al., 2011). Previous research indeed showed that as exercise intensity increases and exceeds the ventilation threshold, most individuals report decreased pleasure and increased displeasure (Ekkekakis et al., 2011). This affective response could be explained by interoceptive feedback resulting from the increased effort including, but not limited to, the release of adrenaline and growth hormone, or the accumulation of inorganic phosphate interfering with muscle function (Allen & Westerblad, 2001; Deijen et al., 2005; Kindermann et al., 1982). Likewise, neuroscientific studies have shown that effort is generally processed as a cost, i.e., an aversive experience to be avoided whenever possible (Hagura et al., 2017; Prévost et al., 2010). Thus, the current study further strengthens the well-validated relationship between effort and direct self-reported measures of affective response.

However, although pleasantness associated with neutral faces was slightly positive, we found no statistical evidence of improved positive affective responses at lower levels of perceived effort. This result contrasts with previous studies that observed an improvement in direct self-reported affective responses at low effort intensities (Ekkekakis et al., 2011). This discrepancy could be explained by differences in the methods of measuring affective responses. In particular, it has been argued that cognitive factors are dominant in shaping affective responses at low effort intensities, while interoceptive cues gain salience when exercise intensity approaches functional limits (Ekkekakis, 2003). This rationale suggests that the positive affective responses reported during low-intensity exercise can reflect a conscious deliberation about one's own affective response rather than the true affective response *per se*. Furthermore, this cognitive reflection about one's own affective state can be biased by normative responses, social pressure, and desirability (Ekkekakis et al., 2018). Accordingly, the self-reported increase in positive affective state when individuals move from rest to low effort intensity could reflect a true increase but could also reflect a self-reported bias. This discrepancy may also be explained by the fact that our task could not discriminate affective responses with the same granularity as direct self-reported measures for at least two reasons. First, to measure pleasantness, we used a Likert scale ranging from one to nine with one-point increments, which prevented the capture of small changes in affective responses. Using another type of scale, such as a visual analogic scale, could offer greater precision. Second, we did not measure the affective responses at rest, which reduced our range of low-intensity effort. In the absence of a rest condition, we can hardly draw conclusions about the results observed at low levels of effort.

Our results investigating the effect of actual effort on incidental affective responses during physical activity were consistent with the main analysis, revealing that higher levels of actual effort were associated with less positive incidental affective responses. However, contrary to the effect of perceived effort, this effect was linear, suggesting a detrimental impact of actual effort on the affective response even when effort was lower (e.g., from a "very easy" to an "easy" bout). This result contrasts with previous studies based on self-reported measures showing that the negative effect of effort intensity on the affective response only emerged at high effort levels (Ekkekakis et al., 2011). Yet, as mentioned above, this difference could be explained by a lack of granularity of our metric compared with the self-reported measures used in prior studies. Most importantly, we did not adjust the actual level of effort for cardiorespiratory fitness. Accordingly, a given level of physical effort (e.g., 241.5 W) may be associated with low effort in some participants, but with high effort in others. This large amount of inter-individual variability may have distorted the observed associations.

Finally, to the best of our knowledge, only one study has sought to capture affective responses during exercise without relying on a direct self-reported measure (Timme & Brand, 2020). This study investigated the facial actions (e.g., mouth open, nose wrinkle) during an incremental physical exercise as indicators of the affective responses. Results showed a quadratic decline in direct self-reported affective valence as exercise intensity increased and observed that nose wrinkle correlated with this negative response. Although the measures (i.e., facial action vs. an indirect measure of affective response to effort) and methods used (i.e., incremental exercise vs. random bouts of exercise intensity) differed between the studies, results were consistent as they support the idea that capturing affective responses during physical activity without relying on the direct self-reported affective response to physical activity is feasible.

At the conceptual level, our findings are in line with previous literature arguing that high-intensity activities are, despite inter-individual differences (Ekkekakis et al., 2005), homogeneously associated with a decreased pleasure. Indeed, engaging in high-intensity physical activity may elicit a negative affective response, which in turn, through the repetition of these negative experiences, become encoded in an individual's evaluative and associative system of memory. In turn, these negative affective evaluations can decrease engagement in physical activity. Consistent with this idea, recent theories contend that affective mechanisms play a pivotal role in explaining the gap between intention and action (Brand & Ekkekakis, 2018; Cheval et al., 2018; Conroy & Berry, 2017). For example, studies showed that affective responses during physical effort predict future engagement in physical activity (Rhodes et al., 2019; Williams & Bohlen, 2019; Williams et al., 2012). Particularly, TEMPA argues that affective responses and perceived effort are strongly intertwined – increased perceived effort is associated with less positive affective responses (Cheval & Boisgontier, 2021; Cheval et al., 2018). According to this theoretical model, positive affective experiences toward physical activity are thought to help individuals to overcome human's innate attraction toward physical effort minimization (Cheval, Bacelar, et al., 2020; Cheval & Boisgontier, 2021; Cheval et al., 2017; Klein-Flügge et al., 2016; Prévost et al., 2010). Practically speaking, promoting engagement in high-intensity physical activity is unlikely to effectively address the public health problem of physical inactivity (Ekkekakis et al., 2011).

Strengths and limiting conditions

We believe that this study has several strengths. First, we relied on a highly powered study. Second, we applied an analytical approach well-suited to examine data with cross-random factors (i.e., participants and faces). Third, we used neutral, negative (anger), and positive faces (happiness) to determine whether the effect of perceived effort on incidental affective responses may depend on the nature of the stimulus to be evaluated, a methodological test rarely done in past studies. Fourth, we have built a design allowing the randomization and repetition of different levels of effort across time, while previous literature mainly relied on incremental exercise. Therefore, contrary to previous literature, our method accounts for a potential effect of time, fatigue, and devaluation of the task on the affective responses. Fifth, we developed an innovative whole-body exercise task under virtual reality combined with a task that indirectly measures affective responses at various levels of effort. Virtual reality allowed us to build knowledge based on an experimental task conducted in a well-controlled setting, while maintaining ecological validity.

However, this study also has limitations. First, we did not include a direct self-reported measure of affective responses. Although adding such measures could have had a confounding effect on the affective evaluations of the neutral faces (i.e., by asking the participants to focus on their affective states), this would have allowed the comparison of a direct self-reported and an indirect self-reported measures of affective responses during physical activity. Second, incidental affective responses are thought to reflect largely automatic and uncontrollable responses. However, even the type of so-called "implicit" or "indirect" task that we have used has been found to be influenced by reflective processes (Corneille & Hütter, 2020; Corneille et al., 2019; Stahl et al., 2016), thereby questioning their validity to target truly automatic mechanisms. Note that the distinction between automatic and controlled processes is not trivial, and that considering that the processes to-be-assessed vary in their degree of automaticity seems less problematic than an "all or nothing" vision. Therefore, it seems more accurate to consider that the proposed task only reflected a more automatic measure of affective responses to physical activity than direct self-reported measures would, as it involved participants' introspective ability to a lesser extent and seems less susceptible to social desirability biases. Finally, although the randomization of the levels of effort is a strength, this design also has limitations. Specifically, there could be a *contagion effect* between blocks: a bout could be associated with more positive affective responses if the previous bout was perceived as pleasant, with a low effort (e.g., switching from a very easy effort to a moderate effort). Alternatively, there could be a *contrast effect*: a bout could be associated with more positive affective responses because the preceding bout was unpleasant and very intense (e.g., switching from a very hard effort to an easier effort). Thus, although the randomization of effort was implemented to minimize these biases, their potential influence on the results cannot be completely excluded.

Conclusion

Beyond a certain level of effort, perceived as light by participants, an increase in perceived effort was associated with a decrease in the pleasantness of neutral faces. This finding supports previous results based on direct self-reports showing that higher intensities of physical activity are associated with decreased affective responses, and extent them to indirect self-reports that are thought to measure more automatic and incidental affective responses.

Declarations

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Competing interests. The authors declare no conflict of interests.

Ethical approval. This study was approved by the Ethics Committee of Geneva Canton, Switzerland (CCER-2019-00065).

Consent to participate. All the participants agreed to participate and signed a written informed consent.

Consent for publication. All the authors have agreed to the by-line order and to the submission of the manuscript in this form.

Availability of data and material. The dataset is available at https://doi.org/10.5281/zenodo.6405782

Code availability. The code is available at https://doi.org/10.5281/zenodo.6405782

Contributors. BC designed the study. SNB and FV collected the data. BC analyzed the data. MD and ML supervised the data collection. BC, SM, MPB drafted the manuscript. MPB supervised the study. All authors critically appraised and approved the final version of the manuscript.

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Supplemental Material

Tables

Table S1. *Results of the mixed models predicting the pleasantness of neutral faces as a function of actual effort*

Table S2. *Results of the mixed models predicting the pleasantness of positive (happiness) faces as a function of perceived effort.*

Table S3. *Results of the mixed models predicting the pleasantness of the negative (anger) faces as a function of perceived effort.*

Table S4. *Results of the mixed models predicting the pleasantness of neutral faces as a function of perceived effort, excluding participants who felt nauseous during the experiment.*

Figures

Figure S1. *Prediction of the pleasantness of neutral faces as a function of actual effort.*

Figure S2. *Prediction of the pleasantness of positive, negative, and neutral faces as a function of perceived effort.*

Figure S3. *Prediction of the pleasantness of positive, negative, and neutral faces as a function of perceived effort, excluding participants who felt nauseous during the experiment.*

Table S1.

Results of the mixed models predicting the pleasantness of neutral faces as a function of actual effort

Pleasantness of the neutral faces		
N = 42	b (95CI)	*p*
Fixed Effects		
Intercept	5.066 (4.832;5.405)	<.001
Perceived effort		
Linear effect	-0.020 (-0.048; -0.005)	.049
Quadratic effect	-0.002 (-0.017; -0.001)	.808
Covariates		
Age	-0.004 (-0.020;0.014)	.648
Sex (ref. men)		
Women	-0.306 (-0.658;0.014)	.096
Body mass index	-0.027 (-0.012;0.070)	.237
Block (ref. Block 1)		
Block 2	-0.029 (-0.027;0.091)	.336
Bout (1-15)	0.002 (-0.002;0.012)	.486
Random Effects		
Participants*		
Intercept	0.225	
Stimuli (Faces)		
Intercept	0.110	
Residual	0.593	
R^2	Marginal = .028; Conditional = .379	

Notes. 95CI = confidence interval at 95%.

* The random effect of perceived effort at the level of participants was not included as the correlation was equal to -1.00, indicating redundancy in the parameters. When this random effect was included, the results remained consistent, but the *p*-value became non-significant (b= -0.020, 95%CI = -0.040 – <0.001, *p* = .055).

Table S2

Results of the mixed models predicting the pleasantness of positive (happiness) faces as a function of perceived effort

Pleasantness of the positive faces		
N = 42	b (95CI)	*p*
Fixed Effects		
Intercept	6.598 (6.239;6.958)	<.001
Perceived effort		
Linear effect	-0.025 (-0.051; 0.001)	.072
Quadratic effect	-0.001 (-0.008; 0.010)	.834
Covariates		
Age	0.001 (-0.021;0.023)	.932
Sex (ref. men)		
Women	0.006 (-0.429;0.441)	.980
Body mass index	0.007 (-0.049;0.612)	.816
Block (ref. Block 1)		
Block 2	-0.089 (-0.154;0.023)	.008
Bout (1-15)	-0.003 (-0.011;0.004)	.372
Random Effects		
Participants		
Intercept	0.362	
Perceived effort	0.002	
Corr. (Intercept, Perceived effort)	0.42	
Stimuli (Faces)		
Intercept	0.037	
Residual	0.728	
R^2	Marginal = .004; Conditional = .365	

Notes. 95CI = confidence interval at 95%.

Table S3

Results of the mixed models predicting the pleasantness of negative (anger) faces as a function of perceived effort

Pleasantness of the negative faces		
N = 42	b (95CI)	*p*
Fixed Effects		
Intercept	3.126 (2.765;3.487)	<.001
Perceived effort		
Linear effect	-0.005 (-0.033; 0.044)	.785
Quadratic effect	-0.002 (-0.012; 0.007)	.618
Covariates		
Age	-0.004 (-0.018;0.003)	.715
Sex (ref. men)		
Women	-0.439 (-0.876;0.002)	.057
Body mass index	-0.008 (-0.047;0.062)	.784
Block (1 vs. 2)	0.116 (0.055;0.178)	<.001
Bout (1-15)	0.006 (-0.001;0.062)	.084
Random Effects		
Participants		
Intercept	0.346	
Perceived effort	0.011	
Corr. (Intercept, Perceived effort)	0.04	
Stimuli (Faces)		
Intercept	0.082	
Residual	0.621	
R^2	Marginal = .048; Conditional = .459	

Notes. 95CI=confidence interval at 95%.

Table S4

Results of the mixed models predicting the pleasantness of neutral faces as a function of perceived effort, excluding participants who felt nauseous during the experiment.

Pleasantness of the neutral faces		
N = 36	b (95% CI)	*p*
Fixed Effects		
Intercept	5.158 (4.876;5.440)	<.001
Perceived effort		
Linear effect	-0.032 (-0.054; -0.009)	.008
Quadratic effect	-0.009 (-0.018; -0.001)	.030
Covariates		
Age	-0.006 (-0.026;0.013)	.547
Sex (ref. men)		
Women	-0.275 (-0.625;0.075)	.134
Body mass index	-0.031 (-0.028;0.009)	.315
Block (ref. Block 1)		
Block 2	-0.005 (-0.070;0.060)	.882
Bout (1-15)	0.002 (-0.005;0.009)	.591
Random Effects		
Participants		
Intercept	0.183	
Perceived effort	<0.001	
Corr. (Intercept, Perceived effort)	-0.19	
Stimuli (Faces)		
Intercept	0.123	
Residual	0.609	
R^2	Marginal = .027; Conditional = .353	

Notes. 95% CI = 95% confidence interval.

Figure S1.

Prediction of the pleasantness of the neutral faces as a function of actual effort. Errors bars represent the standard errors. Dashed line = value corresponding to the neutral evaluation of the face (i.e., 5 on the scale ranging from 1 to 9).

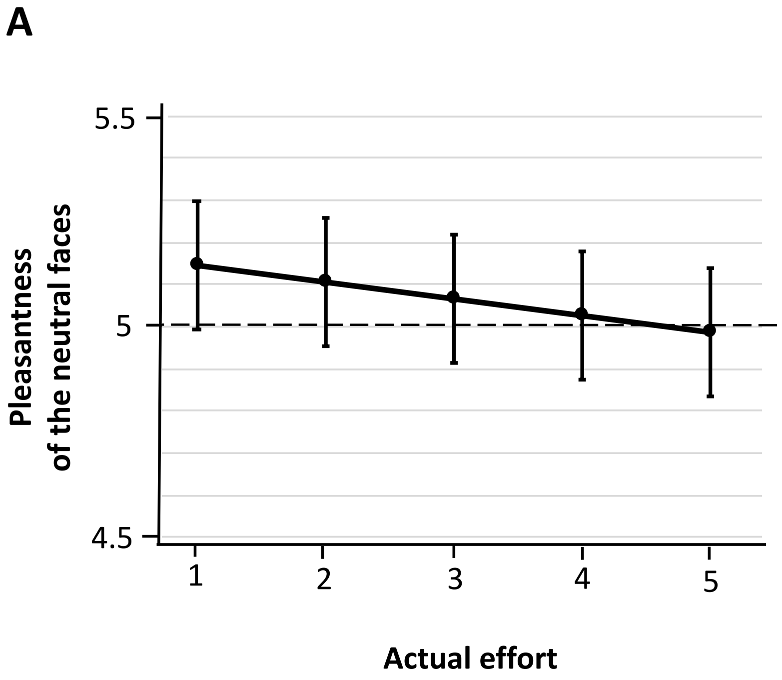

Figure S2.

Prediction of the pleasantness evaluation of positive, negative, and neutral faces as a function of the level of perceived effort. Errors bars represent the standard errors. Dashed line = value corresponding to the neutral evaluation of the face (i.e., 5 on the scale ranging from 1 to 9).

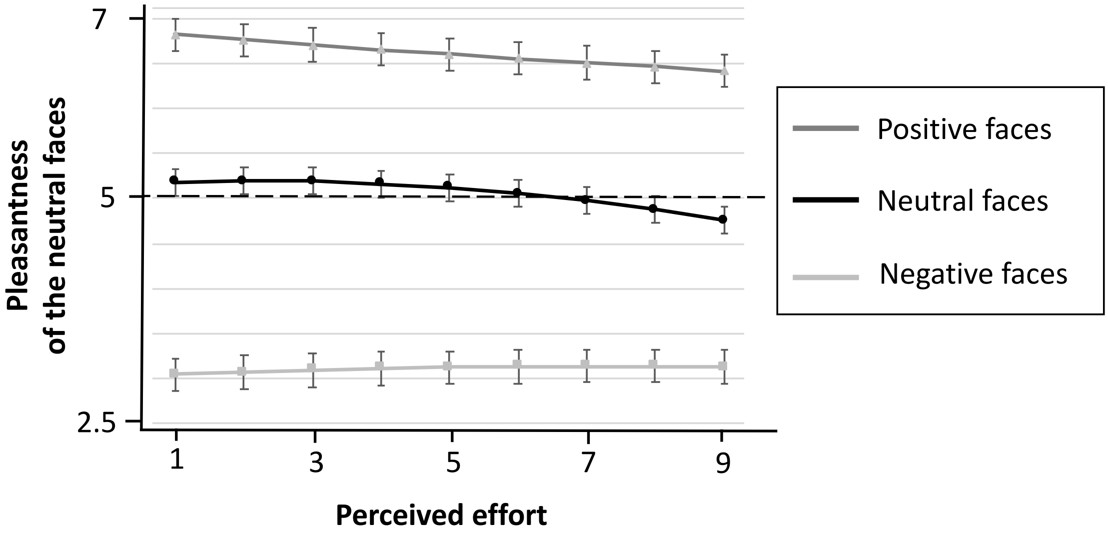

Figure S3.

A. Prediction of the pleasantness evaluation of neutral faces as a function of the level of perceived effort, excluding participants who felt nauseous during the exercise task. Errors bars represent the standard errors. Dashed line = value corresponding to the neutral evaluation of the face (i.e., 5 on the scale ranging from 1 to 9). *B. Region of significance of the effect of perceived effort on the evaluation of the pleasantness of neutral faces as a function of the level of perceived effort, excluding participants who felt nauseous during the exercise task.* A negative coefficient indicates that an increase in perceived effort was associated with a decrease in the evaluation of the pleasantness of the neutral faces; solid line = mean; dashed line= 95% confidence interval; grey area = region of significant (p <.005).