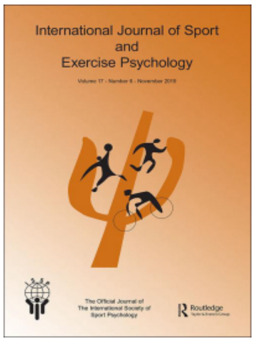

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Can automatic reactions mirror exercise dependence?

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ABSTRACT

While physical activity (PA) has numerous health benefits, in rare cases it can become addictive and lead to adverse health effects. Automatic reactions to addiction-related cues are a hallmark of addiction, however, their association with exercise dependence (ED) remains unknown. This research examined the links between ED and automatic reactions to PA-related cues in physically active individuals with low-to-moderate levels of ED through two studies. Study 1 ($N = 65$) used a dot-probe task with eye-tracking to assess the association between attentional bias toward PA and ED scores measured by the Exercise Dependence Scale-Revised. Study 2 ($N = 125$) used a manikin task and a single-category implicit association test to examine the association of approach-avoidance tendencies and implicit affective attitudes toward PA with ED scores. Results revealed ED scores were positively associated with behavioral indicators of attentional bias (i.e., reaction times), but not with eye-tracking indicators (i.e., first-gaze localization, gaze duration). Similarly, ED scores were unrelated to approach-avoidance tendencies or implicit affective attitudes toward PA. Therefore, our research provides limited evidence supporting the hypothesis that automatic reactions to PA may reflect a "signature" of ED. Our findings do not robustly support the link between automatic processes and ED, raising questions about whether the psychological mechanisms involved in ED might differ from those observed in other addictive behaviors where automatic processes are key. However, due to our sample's low-to-moderate levels of ED, definitive conclusions cannot be drawn. Further research with individuals exhibiting addiction-related dependence, personalized stimuli, and neurophysiological methods is needed.

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The benefits of physical activity (PA) on physical and mental health are now well established (Warburton & Bredin, 2017). PA has been shown to reduce the risk of several conditions, including cardiovascular disease (Wahid et al., 2016), cancer (Moore et al., 2016), diabetes (Wahid et al., 2016), obesity (Hills et al., 2011; Wareham et al., 2005), depression and anxiety (Kandola et al., 2019; Rebar, Stanton, et al., 2015; Schuch et al., 2018), as well as the decline of cognitive function (Cheval et al., 2023; Hillman et al., 2008). Thus, there is widespread agreement that PA is a positive health behaviour that should be encouraged. However, for a small portion of the population – i.e., roughly less than 3% (Hausenblas et al., 2017) – exercise, and more broadly PA, can become excessive and take on a harmful, addictive dimension. The present studies aimed to improve our understanding of the psychological mechanisms that may underlie exercise dependence.

The term "exercise dependence" is used throughout this article to maintain consistency with the instrument used and with the cautionary note made in the literature. While exercise dependence is often adopted as a synonym for exercise addiction, the latter is a two-dimensional construct that includes both dependence and compulsion (Goodman, 1990; Szabo & Demetrovics, 2022). Therefore, when exercise dependence is referred to as exercise addiction, scholars are making an erroneous analogy between a potentially hazardous behaviour and one of its components. In fact, as Goodman (1990) has pointed out, not all dependencies are negative factors in addiction, because high levels of dependency can be controlled (such as exercise for fitness, work for survival, rehabilitation exercise to heal from injury, etc.). The outcome of "controlled" dependence is harmless, but exercise addiction is linked to the loss of control over the exercise behaviour (Szabo & Demetrovics, 2022).

While we use the term "exercise" in this report, the studies reported here focus on PA in general, not just on exercise, which can be defined as a subset of PA that is planned, structured, and repeated (Caspersen et al., 1985). Furthermore, we do not separate exercise from sport, which, in addition to being planned, involves rules and comprises competition. Consequently, our notion of "exercise" refers to "planned physical activities", which is performed on a regular basis.

Exercise dependence

Exercise addiction is characterised by a loss of control so that exercise becomes a perceived obligation and excessive (Hausenblas et al., 2017; Mónok et al., 2012; Szabo et al., 2015). For people with exercise addiction, exercise is compulsive and manifests in symptoms similar to other addictions (Berczik et al., 2012). For example, people living with exercise dependence may need to increase the amount of exercise they do to achieve the same pleasure, experience withdrawal symptoms (e.g., irritability, anxiety, fatigue) when they are forced to suddenly reduce or stop exercising, need to exercise despite persistent or recurrent physical problems such as injury, and report that exercise interferes with other activities such as social, occupational, work, or family activities (Downs et al., 2004; Griffiths et al., 2005). The intensity of these symptoms and the overall risk of exercise dependence can be measured using various scales, including the EDS-R (Downs et al., 2004). This screening, rather than diagnostic (Egorov & Szabo, 2013), scale allows the individuals to be classified into three different categories – nondependent asymptomatic, nondependent symptomatic, and at-risk – based on their score, but can also be used in its continuous form (Hausenblas et al., 2017). In the context of this paper, we will use the continuous form, which allows for a finer degree of ranking dependence symptoms intensity between individuals (i.e., scores from 1 to 6).

Although exercise dependence was initially defined as a "positive addiction" because no harm was expected to result from excessive exercise (Glasser, 1976), it transpired that it could lead to a variety of physical pathologies, including osteoporosis, dysrhythmias, and myocardial fibrosis (Hausenblas et al., 2017). Exercise dependence is also associated with negative psychological effects such as anxiety and depression (Starcevic & Khazaal, 2017). However, despite these multiple detrimental effects, the "dangers" of excessive exercise are overlooked, and risk of exercise dependence remains insufficiently understood (Hausenblas et al., 2017). Importantly, little is known about the mechanisms underlying it.

Automatic processes and addiction

Humans have evolved to behave in ways that increase pleasure and decrease displeasure (Cabanac, 1992; Ekkekakis & Zenko, 2016; Williams & Bohlen, 2019). Part of this process of approaching pleasure and avoiding displeasure occurs without our awareness or intent (Evans, 2008; Evans & Stanovich, 2013). These automatic processes are the result of accumulated learned associations that serve the purpose of initiating rewarding behaviours more efficiently and spontaneously (Rebar, 2017). Indeed, within fractions of a second, we have automatic reactions to visual stimuli around us (Thorpe et al., 1996). For example, emotional stimuli have been found to attract attention, elicit automatic affective responses, and generate an immediate impulse to approach or avoid the stimuli (Krieglmeyer & Deutsch, 2010; Mogg et al., 2003; Pool et al., 2016). In other words, encountering a reward triggers automatic responses (i.e., attentional bias, positive implicit affective attitudes, and approach tendencies) that ultimately favour its consumption (Sander & Nummenmaa, 2021).

Strong automatic reactions to cues related to the addictive behaviour have been identified as a hallmark of addictive use in other contexts, such as illicit drugs and alcohol (Wiers & Stacy, 2006). Thus, automatic reactions to exercise-related stimuli may serve as an indicator of the risk of exercise addiction. According to the incentive sensitisation theory of addiction, as dependence develops, people's motivation becomes largely irrational, driven by automatic processes with little cognitive control (Berridge & Kringelbach, 2008; Robinson & Berridge, 1993; Wiers et al., 2013). This is related to another hallmark of addictive behaviour, the transition from a voluntary to an automatic mode of behavioural regulation, in which cues that predict the addictive behaviour increase in incentive salience (Robinson & Berridge, 1993; Wiers et al., 2014). Consequently, among individuals with an addiction, a cue that has been learned to be associated with the addictive behaviour becomes sought out and triggers the reward system and various automatic reactions (Berridge & Kringelbach, 2008).

Overall, studies have shown that three types of automatic reactions – i.e., attentional bias, implicit affective attitudes, and approach-avoidance tendencies – correlate with levels of dependence in a variety of contexts. For example, regular drinkers, smokers, heroin and marijuana abusers, and gamblers have shown attentional biases for their respective addiction-related stimuli (Field & Cox, 2008; Schoenmakers et al., 2010). In addition, people with alcohol disorders show strong automatic tendencies to approach (vs avoid) alcohol stimuli (Ostafin et al., 2003; Wiers et al., 2010; Wiers et al., 2011). A similar pattern has been found in heavy smokers (Bradley et al., 2008; Wiers et al., 2013), marijuana users (Cousijn et al., 2011), heroin abusers (Zhou et al., 2012), and problem gamblers (Boffo et al., 2019; Brevers et al., 2011), with strong automatic tendencies to approach (vs avoid) stimuli related to their respective addictive stimuli. Finally, several studies have found a direct correlation between positive implicit affective attitudes toward cues associated with the object of dependence and levels of dependence among smokers, regular drinkers, and marijuana abusers (Rooke et al., 2008), as well as among people with internet gaming dependence (Yen et al., 2011) and problem gamblers (Brevers & Noël, 2013). In summary, dependence and automatic reactions to addiction-related stimuli – e.g., attentional biases, implicit affective attitudes, and approach tendencies – have been shown to be intertwined in a variety of contexts. However, it remains unclear whether such automatic reactions are also associated with the risk of exercise addiction.

Automatic processes and physical activity behaviours

Previous studies have shown that automatic reactions toward PA cues are related to PA behaviour. For example, numerous studies have shown that PA levels correlate with attentional biases (Berry, 2006; Berry et al., 2011; Calitri et al., 2009; Cheval et al., 2020), approach (vs avoid) tendencies (Cheval et al., 2014; Cheval et al., 2015; Cheval et al., 2016; Moffitt et al., 2019), and positive implicit affective attitudes (Bluemke et al., 2010; Chevance et al., 2017; Conroy et al., 2010; Rebar, Ram, et al., 2015) toward PA-related stimuli. However, to the best of our knowledge, only one study has examined the relationship between automatic reactions to exercise and exercise dependence (Forrest et al., 2016). Using an adaptation of the Implicit Association Test (Greenwald et al., 1998), whereby participants were asked to classify exercise-related (vs. rest-related) words with words associated with the concept of importance (vs. unimportance), the study showed that people who tended to associate exercise more strongly with the concept of importance reported higher exercise dependence symptoms (Forrest et al., 2016). Although Forrest et al. (2016) provided evidence that there may be automatic biases associated with exercise dependence, the association of exercise dependence with the other automatic indicators identified in previous literature as characteristic of dependence (i.e., attentional biases, implicit affective attitudes, and automatic approach tendencies) remains unknown.

The present research

To fill this knowledge gap, the purpose of the current research was to investigate whether, after accounting for usual level of PA, individuals with higher risk for exercise dependence would exhibit stronger automatic reactions. Specifically, we examined the associations of three specific automatic processes – i.e., attentional biases, approach tendencies, and implicit affective attitudes toward PA cues – with risk of exercise dependence. Two independent studies were conducted. In Study 1, behavioural (i.e., reaction times) and eye-tracking (i.e., first gaze location and gaze duration) measures of attentional bias to stimuli depicting a person exercising (vs. not exercising) were examined in a visual dot probe task with an eye-tracker (Cheval et al., 2020). In Study 2, automatic approach-avoidance tendencies and implicit affective attitudes toward PA behaviours were assessed using a manikin task and a single-category implicit association test (SC-IAT), respectively. To increase the likelihood of observing high risk of exercise dependence, Study 2 included only active individuals (i.e., those who engaged in at least 2–3 hours of moderate-to-vigorous PA per week). Overall, based on the dependence literature, we hypothesised that, after accounting for usual PA, the increase in exercise dependence score would correlate with stronger attentional biases, approach tendencies, and more positive implicit affective attitudes toward exercise-related stimuli. Note that the use of the EDS-R scale in its continuous form (i.e., from 1 to 6), rather than in its categorical form (i.e., nondependent asymptomatic, nondependent symptomatic, and at-risk), makes it possible to examine whether the hypothesised associations can be observed beyond participants classified as "at risk" (Hausenblas et al., 2017). Note that, as discussed, this choice may largely account for the overall lack of consistent associations observed between exercise dependence scores and automatic processes.

All data sets presented below and the scripts for the models tested are available at https://zenodo.org/records/12633064.

Study 1

The aim of Study 1 was to assess the associations of exercise dependence with behavioural (reaction time task to detect a dot) and eye-tracking (first gaze location and gaze duration) indicators of attentional bias toward exercise. These indicators were captured using a visual dot probe task, in which stimuli representing an exercising (vs. non-exercising) individual were presented on the screen (Pauly & Sankar, 2015; Pool et al., 2019; Prévost et al., 2013). Based on the results observed for other addictive behaviours presented above, we hypothesised that, after adjusting for usual level of PA, participants with higher scores on the EDS-R, indicating higher risk for exercise dependence, would be faster to detect the dot when it appeared in the area previously occupied by an exercise stimulus (*H1*), would first direct their gaze toward exercise stimuli (*H2*), and would gaze longer at exercise stimuli (*H3*), compared to participants with lower risk of exercise dependence.

Methods

Participants and procedure

The study design is described in detail elsewhere (Cheval et al., 2020). Briefly, the study involved 84 young healthy students from the University of Geneva. All participants were first asked to complete questionnaires measuring, among other things, their usual level of PA and their risk of exercise dependence. They were then asked to perform a visual dot probe task while being assessed by an eye tracker. Participants with a history of psychiatric, neurological, or severe mental disorders and with uncorrected visual impairment were excluded. Participants with low levels of PA according to the International Physical Activity Questionnaire (IPAQ; Craig et al., 2003) scoring protocol (i.e., less than 600 MET minutes/week of total PA) were excluded from analyses, as a moderate level of PA is considered a necessary condition to observe at least moderate levels of exercise dependence (Cheval et al., 2020). This study was approved by the ethics committee of the University of Geneva.

The sample size was determined for the original study. Therefore, we used all the available data in the current study. Of the 84 participants, 19 were considered not eligible because of low PA levels and were excluded, resulting in a final analyzed sample of 65 physically active participants. To ensure that the study was adequately powered to detect the effect of interest, a sensitivity power analysis was performed using G*Power 3.1 (Faul et al., 2009). We estimated power for an ANOVA: within-between interaction; set $\alpha = .05$; set groups = 2; set measures = 2; a correlation between repeated measures of $r = .5$, and a non-sphericity correction = 1. The results showed that with a sample of $N = 65$, we have a statistical power of 97% to detect an interaction between risk of exercise dependence and attentional bias toward PA (vs. physical inactivity) stimuli.

Material and measures

Exercise Dependence Score. The risk of exercise dependence was assessed using the validated French version of the Exercise Dependence Scale – Revised (EDS-R; Kern, 2007). This multidimensional scale measures symptoms of exercise dependence according to the operationalised DSM-IV behavioural dependence criteria for exercise dependence (Downs et al., 2004). It contains 21 items divided into seven subscales to assess different dimensions of dependence (i.e., withdrawal, continuance, tolerance, lack of control, reduction in other activities, time, and intention effect). Participants answered each item on a 6-point Likert scale ranging from 1 (*never*) to 6 (*always*). Items were averaged to create a global score, with higher scores indicating stronger risk for exercise dependence (Cronbach's $\alpha = .93$).

Attentional Bias Responses in the Visual Dot Probe Task. The visual dot probe task, which is used to measure the attentional bias toward PA (vs. inactivity) stimuli using eye-tracking, is described in detail in Cheval et al. (2020). We used an infrared corneal reflection eye-tracker Tobii 1750 (Tobii Pro AB, Danderyd, Sweden), which provides a non-invasive measurement of fixation times using corneal reflection to detect oculomotor movements. The system records near-infrared reflections of both eyes at 60 Hz, with an accuracy of 0.5 degrees and a spatial resolution of 0.1 degree.

In the dot-probe task, each trial began with a fixation cross in the center of the white background screen. Then, the fixation cross disappeared and two pictures (one of an individual exercising and one of an individual not exercising) were randomly presented on the left and right side of the screen for 4000–4500 ms. This longer-than-usual presentation time was chosen to allow participants sufficient time to navigate the two images on the screen, which has been shown to increase the reliability of the eye movement metrics (Waechter et al., 2014). A black dot was then presented on either the left or o the right side of the screen. Participants had to press the "S" or "L" key as quickly as possible with their left or right index finger when the dot appeared on the left or right, respectively. The dot remained on the screen until the participant responded. After the participant responded, the next trial began immediately (Figure 1). The task consisted of 6 training trials and 80 experimental trials. In half of the trials, the dot appeared on the side of the stimuli depicting the person exercising. In the other half, the dot appeared

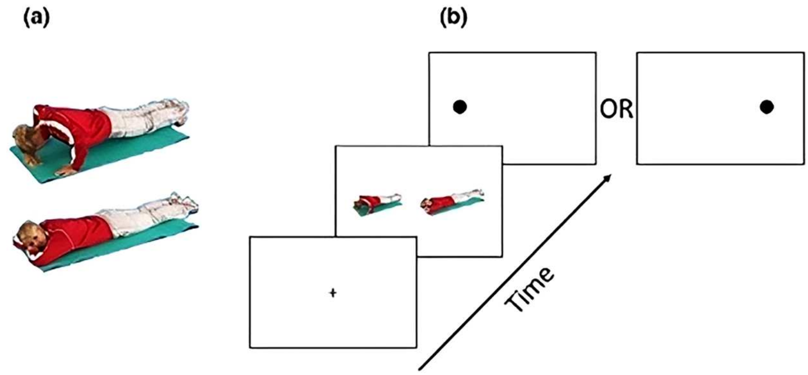

Figure 1. Visual Dot Probe Task and Procedures. *Note.* (a) A pair of stimuli representing a physically active and a physically inactive woman. (b) Procedure. Trials began with a fixation cross for 800 to 1100 ms. Then, stimuli representing physical activity and inactivity appeared for 4,000–4,500 ms on either side of the fixation cross. Then, the stimuli disappeared, and a black dot replaced either the physical activity or inactivity stimulus. Participants were instructed to indicate the side on which the dot appeared, as quickly as possible.

on the side of the stimuli depicting the person not exercising. Trials were presented in a randomised order, and the position of the dot and the type of stimulus were counterbalanced with respect to appearing on the left or right side of the screen. For each trial, we recorded the following variables: (a) log-transformed reaction times for dot detection (i.e., the time elapsed between the appearance of the dot on the screen and the participant's response), (b) initial gaze location (i.e., attentional orientation), and (c) gaze duration (i.e., attentional engagement) (Pool et al., 2016). The initial gaze position was calculated based on a fixation of 100 ms as automatically implemented by the eye-tracking software. The velocity criterion was not used to determine that gaze had shifted away from the stimulus, but we relied on the fact that both eyes had shifted away from the AOI. Gaze duration was calculated over the entire stimulus presentation, not just the first fixation. This comprehensive measure allowed us to capture the total engagement with the stimulus, which improves the reliability of this eye movement metric (Waechter et al., 2014). The procedure for obtaining each indicator from the raw eye tracking data is described in the R script available at https://zenodo.org/records/12633064.

The split-half internal consistency coefficient, adjusted using the Brown-Spearman prophecy formula, was computed and indicated a low reliability for reaction times, ($r_{adjusted} =$ 0.46) but a high reliability for gaze duration ($r_{adjusted} = 0.82$).

Covariate: Usual Level of Physical Activity. Usual level of PA was measured using an adapted version of the IPAQ (Craig et al., 2003), which used two items to assess the time spent in moderate and in vigorous PA during leisure time in a typical week. Time spent in moderate-to-vigorous PA and its MET minutes/week equivalent were calculated according to the IPAQ scoring protocol. Participants who reported less than 600 MET minutes/week of total PA were classified as having low activity levels.

Statistical analysis

Associations of exercise dependence score with reaction time, gaze location, and gaze duration were analyzed using mixed-effects models to account for the cross-random effects (participants and stimuli) and to reduce the risk of type I error (Boisgontier & Cheval, 2016; Judd et al., 2012). Mixed-effects models were run using the *lme4* and *lmerTest* packages in *R* (version 3.6-3), specifying both participant-level and stimulus-level random factors (Bates et al., 2014; Kuznetsova et al., 2015). Effect size estimates are reported using the conditional pseudo-R^2 calculated using the *MuMin* package (Barton, 2018). Statistical assumptions of normality of the residuals, linearity, multicollinearity, and undue influence were met for all models.

Results

Descriptive results

The final sample size included 65 participants (45 women and 20 men; *M* age 21.9 ± 3.2 years; *M* body mass index 21.3 ± 3.1 kg/m^2). The mean usual level of moderate-to-vigorous intensity PA was 232 min per week (±273 min; median = 150). The mean exercise dependence score was 2.5 (± 0.9, range 1.1–4.5 on a 1–6 scale, where 6 indicates strongest risk of dependence). Five (i.e., 7.7%) participants had scores greater than 4 (i.e., classified as at-risk for exercise dependence). Forty participants (i.e., 61.5%) had scores between 2 and 4 (i.e., nondependent-symptomatic) and twenty participants (i.e., 30.8%) had scores below 2 (i.e., nondependent-asymptomatic). Overall, the final sample displayed low-to-moderate scores of exercise dependence (detailed descriptive statistics and distributions are available in Table 1 and Figures S2–S4 in Supplemental Materials).

Attentional bias measures and exercise dependence score

Behavioural Indicator. Results revealed a statistically significant two-way interaction between the location of the dot (which appeared in the area previously occupied by a stimulus depicting a person exercising vs. not exercising) and participants' exercise dependence score, demonstrating that the effect of dot location on reaction time varied as a function of the risk of exercise dependence, $b = -.02$, 95% Confidence Interval (95CI) = [−.03; −.01], $p = .006$ (see Table 2). As expected, simple effects tests showed that when the exercise dependence score was relatively low (−1 *SD*; 1.6 on the EDS-R) or moderate (mean; 2.5 on the EDS-R), participants were not significantly faster to detect a dot appearing in the area previously occupied by a stimulus depicting the person exercising (vs. not exercising) ($b = .01$; 95CI = [−.01; .02]; $p = .385$ and $b = -.01$; 95CI = [−.02; .01]; *p*

Table 1. Descriptive statistics.

	Study 1 *(N = 65)*			Study 2 *(N = 125)*		
Variables	Mean	*SD*	Range	Mean	*SD*	Range
Gender		45 W – 20 M			82 W – 42 M – 1 OTH	
Age *(years)*	21.9	3.2	*18–38*	25.3	8.1	*18–55*
PA time *(min per week)*	672	620	*160–2200*	827	468	*105–2700*
MVPA time *(min per week)*	232	273	*0–1360*	538	330	*75–1500*
Dependence score *(1–6 scale)*	2.5	0.9	*1.1–4.5*	2.7	0.8	*1.2–5.4*

Note. *SD* = Standard deviation; MVPA = Moderate-to-vigorous physical activity; PA = physical activity; PA time represents the total time spent doing PA, including light PA such as walking, as well as MVPA time.

= .108, for low and moderate score exercise dependence, respectively). In contrast, participants with higher risk of dependence (+1 *SD*; 3.6 on the EDS-R) were faster at detecting the dot when it appeared in the area previously occupied by a stimulus depicting a person exercising (vs. not exercising) ($b = -.03$; 95CI = [−.04; −.01]; $p = .002$) (Figure 2). Results of the region of significance test further showed that the shorter time to detect a dot appearing in the area previously occupied by a stimulus depicting the person exercising (vs. not exercising) became significant when the dependence score was greater than 2.8 on the EDS-R.

First Gaze. Results showed a significant effect of usual PA level on the spatial location of the first gaze following the location of the fixation cross (Table 2). The odds of gazing first at a stimulus depicting a person exercising (vs. not exercising) increased as usual PA level increased (odds ratio [OR] = 1.10, 95CI = [1.01; 1.20], $p = .023$). In contrast, the exercise dependence score was not related to the spatial location of the first gaze (OR = 0.96, 95CI = [0.88; 1.05], $p = .393$).

Gaze Duration. Results showed an effect of usual PA level on the time spent looking at the stimuli (Table 2). The viewing time of a stimulus depicting a person exercising (vs. not exercising) increased with increasing usual level of PA ($b = 4.83$, 95CI = [0.39; 9.27], $p = .037$). In contrast, exercise dependence score was not related to the gaze duration ($b = 0.99$, 95CI = [−3.48; 5.45], $p = .666$).

Interim discussion

Among our sample of participants with low-to-moderate scores of exercise dependence, results of Study 1 showed that risk of exercise dependence was associated with the behavioural indicator of attentional bias toward exercise – participants with

Table 2. Results of the mixed models predicting behavioural (reaction times in log) and eye-tracking (First Gaze, Gaze Duration) attentional processes.

	Model: Reaction time (log) to detect the dot		Model: Probability to first gaze at active vs. inactive stimuli		Model: Relative viewing time toward active vs. inactive stimuli	
	b (CI)	*p*	OR (CI)	*p*	b (CI)	*p*
Reaction time						
Fixed effects						
Intercept	6.08 (6.04; 6.11)	<.001	1.35 (1.13; 1.62)	.001	13.42 (6.64; 20.21)	.001
Dot side (ref. on inactive stimuli)	−0.01 (−0.02; 0.01)	.108				
Exercise dependence score	−0.02 (−0.06; 0.02)	.332	0.96 (0.88; 1.05)	.393	0.988 (−3.48; 5.45)	.666
Dot side*Exercise dependence score	−0.02 (−0.03; −0.01)	.006				
Usual time of PA	0.02 (−0.02; 0.06)	.294	1.10 (1.01; 1.20)	.023	4.83 (0.39; 9.27)	.037
Random effects	σ^2		σ^2		σ^2	
Participants						
Intercept	$1.7e^{-2}$		$1.8e^{-2}$		187.1	
Dot side	$8.9e^{-4}$					
Corr. (Intercept, Dot side)	-.13					
Stimuli						
Intercept	$4.3e^{-17}$		$7.0e^{-2}$		82.4	
Residual	$3.1e^{-2}$				2769.0	
R^2	.364		.029		.098	

Note. CI = 95% confidence interval, OR = odds ratio, Corr. = correlation

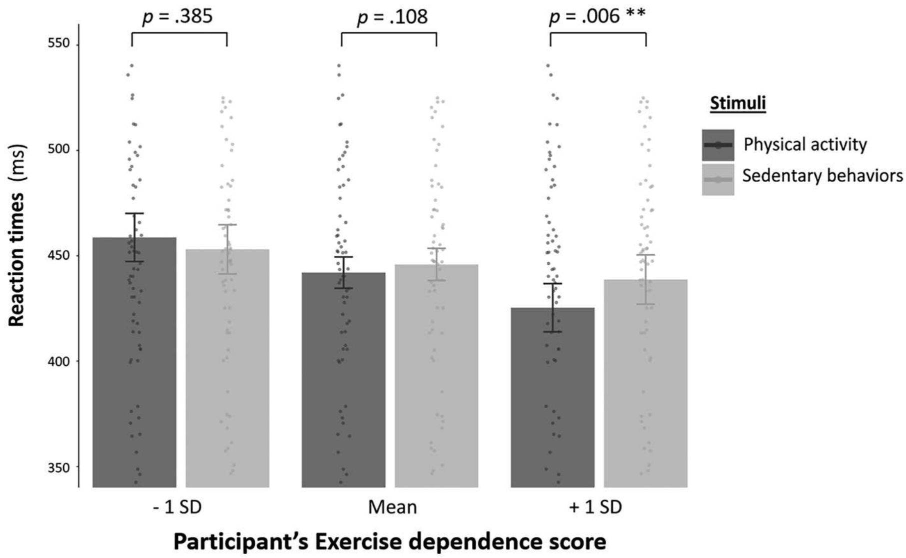

Figure 2. Reaction Times (ms) to Detect the Dot According to Stimuli (Physical Activity vs. Inactivity) and Risk of Exercise Dependence (Arbitrary Units). *Note.* SD = Standard deviation, ms = milliseconds. Reaction times (ms) to detect the dot when it appeared in the area occupied by physical activity (vs. inactivity) stimuli as a function of participant's risk of exercise addiction. ** $p < .01$

higher risk of dependence were faster at detecting the dot when it appeared. In contrast, eye-tracking results showed that usual PA, but not exercise dependence score, was associated with eye-tracking indicators of attentional bias (i.e., first gaze and gaze duration). The discrepancy in the results may be explained by the characteristics of the measures used. While the visual dot-probe task is generally considered to be indicative of attentional bias and is often used to assess it, other studies have suggested that this task lacks validity and reliability (Rodebaugh et al., 2016; Schmukle, 2005; Waechter et al., 2014), as typically observed in implicit measures (Gawronski & De Houwer, 2014). Although in our study the more direct eye-tracking measure of attentional bias provided greater reliability ($r_{adjusted} = 0.82$) than the indirect behavioural one based on reaction times ($r_{adjusted} = 0.46$), our results should still be evaluated in the light of the limitations of the task.

Study 1 was conducted as a preliminary test of the potential associations between automatic reactions to PA-related stimuli and exercise dependence. The sample was not specifically selected based on intensive exercise training and had relatively low score of exercise dependence as measured with the EDS-R. Therefore, no definitive conclusions can be drawn, and the results should be interpreted with caution. Study 2 aimed to assess two other automatic reactions and was designed to include a sample of more physically active individuals than Study 1, recruited from populations who are typically highly active.

Study 2

The purpose of Study 2 was to assess the associations of the exercise dependence score with approach tendencies toward PA using a manikin task, and with implicit affective attitudes toward PA using a SC-IAT. We hypothesised that, after adjusting for usual PA level, participants with higher scores on the EDS-R, indicating higher risk for exercise dependence, would approach (vs. avoid) PA-related stimuli more quickly (H4) and have more positive implicit affective attitudes toward exercise-related stimuli (H5), compared to participants with lower risk of exercise dependence.

Methods

Participants and procedure

Sample size was determined with a power calculation using G*Power 3.1 (Faul et al., 2009). We used the ANOVA: repeated-measures, within-between factors statistical test; set $a = .05$, $1\text{-}b = .90$, groups = 2, measures = 2, and Cohen's d effect size = 0.5. The power calculation estimated a required $N = 46$, which we rounded up to 60 to account for lost data (e.g., due to poor or incomplete data). However, the study remained open for two months, and data collection was not stopped prior to this period, regardless of the amount of data collected.

For this online study, participants living in France or Switzerland were recruited through multiple strategies to ensure a diverse and physically active participant pool. Some participants were recruited through the Psychology Department Research Subject Pool of the University of Geneva, which offers course credit. Other participants were recruited through posters, social media, and word of mouth, specifically targeting populations expected to be more physically active such as sports science students, sports club, fitness centers, and gym members. After presentation of the inclusion criteria (e.g., engaging in regular PA) and a brief introduction to the study, participants were invited to participate by accessing the study via a URL in the email. They were asked to complete the study procedures on a computer in a quiet environment. Basic information and the estimated time to complete the study were presented on the first page of the website. All participants gave their consent and were then asked to complete a short online questionnaire (approximately 10 min) using a secure web survey hosted by the University of Geneva. This questionnaire included questions to assess PA profile (e.g., inactive, regular activity), usual level of PA (in minutes per week), risk of exercise dependence, and other information (e.g., PA habits, intention to engage in PA). At the end of the questionnaire, a secure link to the Inquisit® software was provided to complete two online reaction time tasks assessing approach-avoidance tendencies and implicit affective attitudes toward PA (approximately 15 min). Immediately following the tasks, participants completed a short questionnaire (approximately 2 min) assessing some potential confounding variables (e.g., PA during the previous and current day, current injury, visual impairment, French fluency). Questionnaires were hosted on the secured web LimeSurvey of the University of Geneva.

We excluded participants with missing data due to study incompleteness or technical problems ($N = 204$) and participants who did not engage in regular PA according to the Saltin-Grimby Physical Activity Level Scale (Grimby et al., 2015; i.e., less than 2–3 hours per week of moderate-to-vigorous PA; $N = 108$). In addition, participants who indicated that their data should not be used for research ($N = 14$) and participants with a history of psychiatric, neurological, or severe mental disorders, with uncorrected visual impairment, or who were not fluent in French (N = 4) were excluded.

The final eligible sample included 125 participants (see flowchart Figure S1 in supplemental materials). This research was approved by University of Geneva Ethics committee.

Material and measures

Exercise Dependence Score. We used the same measure as in Study 1.

Automatic Reactions. Two reaction time tasks were used to examine automatic reactions to exercise-related stimuli. A manikin task (Cheval et al., 2014; De Houwer et al., 2001; Krieglmeyer & Deutsch, 2010) was used to measure approach-avoidance action tendencies toward PA and sedentary behaviours, and a SC-IAT (Karpinski & Steinman, 2006) was used to measure implicit affective attitudes toward PA. The tasks were designed using Inquisit®.

Approach and Avoidance Tendencies. In the manikin task, each trial began with a black fixation cross presented randomly for 250–750 ms in the center of a white background screen. The manikin then appeared in the upper or lower half of the screen. Then, 500 ms later, a stimulus representing PA or sedentary behaviour was presented in the center of the screen. Participants were asked to move the manikin "toward" stimuli representing PA (approach) and "away from" stimuli representing sedentary behaviour, or vice versa. Participants were instructed to respond as quickly and as accurately as possible. If the response was correct, the manikin was shown in its new position for 500 ms, and then the screen was cleared. If the response was incorrect or the participant was too slow to respond (i.e., > 3000 ms), error feedback or "too slow" feedback appeared in the center of the screen (Figure 3). The task was administered in two blocks. Each block consisted of 12 practice trials and 48 critical trials. Within the critical trials of each block, all stimuli were presented four times, twice with the manikin presented in the upper half of the screen, and twice with the manikin presented in the lower half of the screen. In one block, participants were instructed to make the manikin approach PA stimuli and avoid sedentary stimuli (i.e., approach block). In the other block, participants were instructed to make the manikin avoid PA stimuli and approach sedentary stimuli (i.e., avoidance block). Participants were asked to press the "U" key with one index finger to move the manikin up and the "N" key with the other index finger to move the manikin down. Participants were asked to respond as quickly as possible while making as few errors as possible. The order of the blocks was counterbalanced across participants, and the stimuli appeared in a random order within each block. The split-half internal consistency coefficient, adjusted with the Brown-Spearman prophecy formula, indicated a good reliability ($r_{adjusted} = 0.68$).

Implicit Affective Attitudes. In the SC-IAT, each trial began with a 250 ms black screen. A word stimulus then appeared in the center of the screen. Specifically, participants were asked to quickly sort words belonging to three conceptual categories: a target category (i.e., physical activity in this study) and two attribute categories (i.e., "good" and "bad"). The attribute categories were presented in the upper-left ("good") and upper-right ("bad") corners of a black screen. In one block, the PA category was presented on the left (i.e., compatible condition; "good or physical activity"), and in the other block, it was presented on the right (i.e., incompatible condition: "bad or physical activity"). Participants were asked to press the key "E" with their left index finger if the displayed word belonged to a category presented on the left, and to press the key "I" with their right

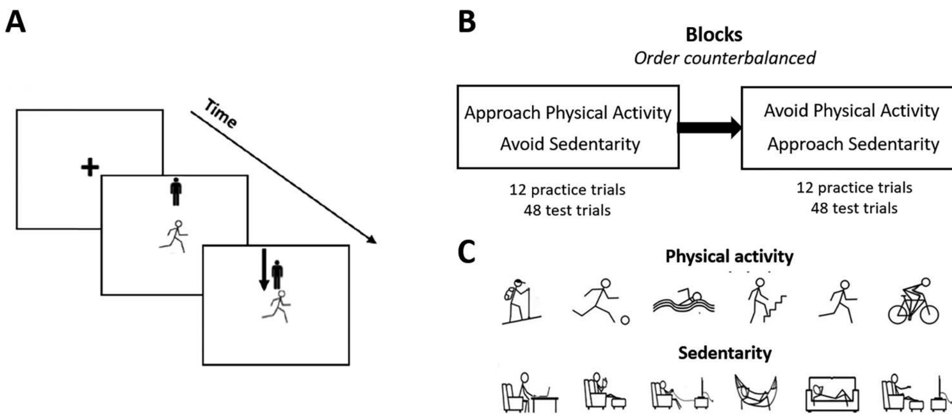

Figure 3. Manikin Task and Procedures. *Note.* (A) Manikin task. Trial in which the participant is asked to approach a stimulus representing physical activity. (B) Description of the procedure for the Manikin task. The order of the blocks was counterbalanced across participants. (C) Stimuli set of six pictures representing physical activity behaviours on the top line and six images representing sedentary behaviours on the bottom line.

index finger if the word belonged to a category presented on the right. If the response was incorrect or if participants responded too slowly (i.e., >2000 ms), error feedback (i.e., a red cross) or slow feedback (i.e., "Please respond more quickly") appeared below the stimulus for 150 ms. If the response was correct, correct feedback (i.e., a green cross) appeared below the stimulus in the center of the screen, and then the next trial began. The SC-IAT was administered in two blocks, each consisting of 24 practice trials and 72 critical trials (Figure 4). The split-half internal consistency coefficient, adjusted with the Brown-Spearman prophecy formula, indicated a good reliability ($r_{adjusted} = 0.71$).

Covariate: Usual Physical Activity. The measure was the same as in Study 1, except that we explicitly added a category measuring sports-related PA.

Statistical analysis

We followed the same analysis strategy as in Study 1, using mixed-effects models to test the associations of exercise dependence score with the two automatic reactions (i.e., approach-avoidance tendencies and implicit affective attitudes).

Results

Descriptive results

The final sample included 125 participants (82 women, 42 men, 1 other; *M* age = 25.3 ± 8.1 years). The mean usual level of MVPA was 538 min per week (±330 min; median = 450), higher than in Study 1 (232 min per week; ±273 min; median = 150). The mean exercise dependence score was 2.7 (± 0.8, range 1.2–5.4 on a 1–6 scale). Ten (i.e., 8%) participants had scores greater than 4 (i.e., at-risk for exercise dependence), while eighty-seven (i.e., 69.6%) had scores between 2 and 4 (i.e., nondependent-symptomatic) and twenty-eight (i.e., 22.4%) had score below 2 (i.e., nondependent-asymptomatic). Overall, despite higher levels of PA, the final sample displayed low-to-moderate exercise

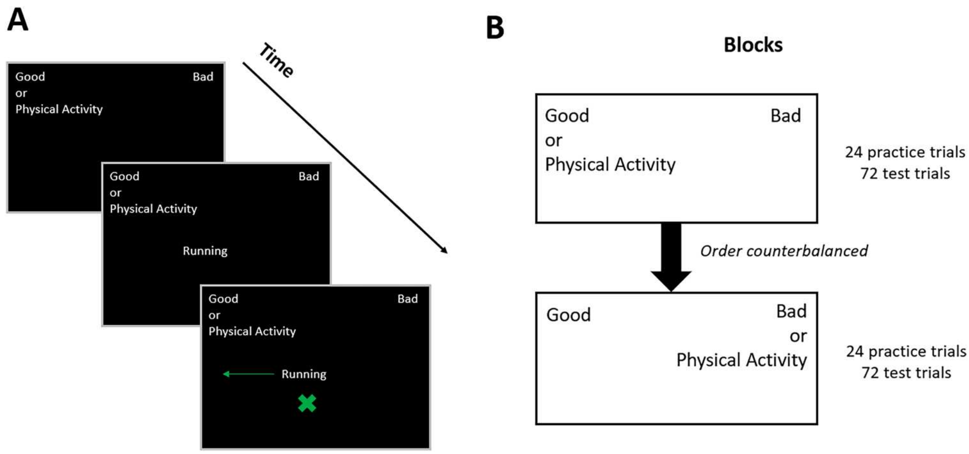

Figure 4. Single-Category Implicit Association Test (SC-IAT) Task and Procedures. *Note.* (**A**) SC-IAT task. A compatible block trial in which the participant is asked to associate physical activity words with the categories "Good or Physical Activity". (B) Procedures. Description of the procedure for the SC-IAT task. The order of the blocks was counterbalanced across participants.

dependence scores, similar to those found in Study 1 (detailed descriptive statistics and distributions are available in Table 1 and Figures S2–S4 in Supplemental Materials).

Automatic reactions

Approach (vs. Avoidance) Tendencies. Results showed a significant two-way interaction between action (i.e., approach vs avoid) and stimuli (i.e., PA vs. sedentary stimuli) ($b = -82.72$; 95CI = [−115.53; −49.91], $p < .001$). Simple slope analysis indicated that participants were faster to approach than to avoid PA stimuli ($b = -95.25$; 95CI = [−114.57; −75.93], $p < .001$), but were no faster to approach than avoid sedentary stimuli ($b = -12.53$; 95CI = [−29.67; − 4.61], $p = .155$). However, there was no evidence that exercise dependence score, or usual PA, had a main or interactive effect (i.e., with action or stimuli) on participants' reaction times (see Table 3). Of note, post hoc secondary analyses were conducted excluding usual PA. Results were consistent with those of the main analysis, with no main or interactive effect of exercise dependence score on participants' reaction times.

Implicit Affective Attitudes. Results showed a main effect of block ($b = -88.36$; 95CI = [−100.63; −76.09], $p < .001$), indicating that participants responded faster for the compatible block (i.e., "physical activity" associated with "good") than for the incompatible block (i.e., "physical activity" associated with "bad"). However, there was no evidence that exercise dependence score, or usual level of MVPA, had a main or interactive effect with the type of block on participants' reaction times (see Table 4). Of note, unplanned secondary analyses were conducted without including usual PA. Results were consistent with those of the main analysis, with no main or interactive effect of exercise dependence score on participants' reaction times.

Interim discussion

Contrary to our hypotheses, results of Study 2 showed that exercise dependence score was not correlated with either approach-avoidance tendencies or implicit affective

Table 3. Results of the linear mixed model predicting the reaction times to approach and avoid stimuli representing physical activity and sedentary behaviours as a function of the risk of exercise dependence, adjusted for the usual level of moderate-to-vigorous physical activity.

Variables Fixed effects	b (CI)	*p*
Intercept	649.79 (630.66; 668.92)	<.001
Action (approach vs. avoidance)[1]	−12.53 (−29.68; 4.62)	.155
Stimuli[2]	40.69 (23.21; 58.17)	<.001
Exercise dependence [3]	−3.88 (−25.83; 18.07)	.730
MVPA[3]	−13.49 (−35.20; 8.20)	.226
Action*Stimuli	−82.72 (−115.53; −49.91)	<.001
Action*Stimuli*Dependence	−21.16 (−58.99; 16.67)	.275
Action*Stimuli*MVPA	−5.41 (−42.92; 32.10)	.778
Random effects	σ^2	
Participants		
Intercept	$9.73e^3$	
Action	$6.70e^3$	
Stimuli	$6.80e^3$	
Action*stimuli	$2.79e^4$	
Correlations		
Intercept, Action	-.05	
Intercept, Stimuli	.10	
Action, Stimuli	.86	
Stimuli (i.e., each stimulus)		
Intercept	6.49	
Residual	$2.21e^4$	–
R^2	.403	–

Note. CI = 95% confidence interval; MVPA = Moderate-to-vigorous physical activity.
[1]−1 = avoidance; 1 = approach; [2]−1 = sedentary behaviours; 1 = physical activity; [3]continuous variables.

attitudes toward PA – i.e., we found no evidence that, after accounting for usual levels of PA, participants with higher scores on the EDS-R, indicating higher risk for exercise dependence, were faster to approach (vs. avoid) PA stimuli or had stronger positive implicit

Table 4. Results of the linear mixed model predicting the reaction times to categorise stimuli in the “Good or Physical Activity” category (compatible block) and in the “Bad or Physical Activity” category (incompatible block) as a function of the risk of exercise dependence, adjusted for the usual level of moderate-to-vigorous physical activity.

Variables		
Fixed effects	b (CI)	*p*
Intercept	722.07 (701.74; 742.40)	<.001
Block (compatible vs. incompatible) [1]	−88.36 (−100.63; −76.09)	<.001
Exercise dependence[2]	0.05 (−20.35; 20.45)	.996
MVPA[2]	0.38 (−20.00; 20.76)	.971
Block*Dependence	−4.46 (−18.20; 9.28)	.526
Block*MVPA	−3.51 (−17.25; 10.23)	.618
Random Effects	σ^2	
Participants		
Intercept	$9.60e^3$	
Block	$3.66e^3$	
Correlation (Intercept, Block)	−.48	
Stimuli		
Intercept	$5.15e^2$	
Residual	$2.88e^4$	–
R^2	.277	–

Note. CI = 95% confidence interval; MVPA = Moderate-to-vigorous physical activity; SC-IAT = Singe-Category Implicit Association Test.
[1]−1 = incompatible; 1 = compatible; [2]continuous variables.

affective attitudes toward PA. Overall, study 2 did not provide empirical support for the hypothesis that the risk of exercise dependence is associated with these automatic reactions. However, due to the low-to-moderate levels of exercise dependence score exhibited in our sample, results must be interpreted with caution. Possible explanations for these non-significant associations are discussed below.

General discussion

Main findings

The purpose of the two studies was to examine potential associations between automatic reactions to PA-related cues – i.e., attentional biases, approach tendencies, and implicit affective attitudes – and risk of exercise dependence. Two independent studies were conducted among physically active individuals with low-to-moderate scores of exercise dependence. We observed that exercise dependence score was associated with a behavioural indicator of attentional bias (i.e., reaction times), but not with more direct eye-tracking indicators (e.g., first-gaze localisation, gaze duration) (Study 1). Moreover, we found no evidence that exercise dependence score was associated with approach-avoidance tendencies or implicit affective attitudes toward PA (Study 2). Therefore, this study suggests that exercise dependence may be associated with one form of automatic process but did not provide enough support for the hypothesis that automatic reactions to PA cues may reflect a "signature" of exercise dependence. However, given the characteristics of our sample – i.e., low score of exercise dependence – no definitive conclusions can be drawn.

Comparison with previous studies

In Study 1, we found that an indirect indicator of attentional bias toward PA – i.e., the difference in reaction time to detect a dot appearing after a PA (vs. physical inactivity) image – was positively associated with exercise dependence score, after adjusting for usual PA level. While this study of attentional biases was, to our knowledge, the first to be conducted with consideration of the risk of exercise dependence, this finding is consistent with previous studies showing that individuals with dependence typically show an attentional bias toward cues related to the object of addiction, such as alcohol, cigarettes, or marijuana (Brevers et al., 2011; Field et al., 2004; Field & Cox, 2008; Rooke et al., 2008). However, we found no evidence that the exercise dependence score was associated with more direct and reliable indicators of attentional biases (i.e., eye-tracking outcomes including first gaze and gaze duration). Reliability concerns have been raised for behavioural measures (Ataya et al., 2012; Jones et al., 2018) and were confirmed to be low in our study ($r_{adjusted} = 0.46$ for reaction times). Therefore, the current results did not provide sufficiently robust evidence that attentional bias toward PA can serve as an indicator of exercise dependence risk. The most likely explanation is that we did not examine a sample composed of highly dependent and excessive exercisers. Furthermore, it is important to remind that the dot-probe parameters used in this study (i.e., stimulus presentation lasting 4000–4500 ms) to promote the reliability of eye-tracking metrics (Waechter et al., 2014) are rather unusual, making direct comparisons with the literature difficult.

Similarly, in Study 2, we found no evidence that the risk of exercise dependence was significantly related to approach-avoidance tendencies toward PA and sedentary stimuli. This finding differs from previous studies showing that individuals with substance dependence (Field & Cox, 2008; Wiers et al., 2010; Zhou et al., 2012) or pathological gambling (Boffo et al., 2019; Brevers & Noël, 2013) show a tendency to approach (rather than avoid) stimuli related to the object of dependence – although null results have also been reported (Cousijn et al., 2011; Cousijn et al., 2012). Notably, in their study, Cousijn et al. (2012) did not find an association at the behavioural level. However, analyses of neurophysiological data showed that activation of several brain regions during an approach-avoidance task under functional magnetic resonance imaging was associated with cannabis use and the severity of cannabis-related problems. These findings raise the possibility of latent effects in our study due to the absence of neurophysiological measures. Thus, incorporating neuroimaging methods alongside behavioural assessments may be warranted before drawing definitive conclusions about the lack of associations between risk of exercise dependence and automatic responses. This is consistent with the general call for more neurophysiological research in exercise psychology (Cheval et al., 2021; Cheval & Boisgontier, 2021; Cheval, Radel, et al., 2018; Cheval, Tipura, et al., 2018; Parma et al., 2023).

At last, in line with the lack of associations observed with approach-avoidance tendencies, we did not find that exercise dependence score was associated with implicit affective attitudes toward PA. Our results contrast with previous work that has found significant and positive associations between implicit affective attitudes and levels of dependence in several other contexts, such as substance abuse (Rooke et al., 2008), Internet gaming (Yen et al., 2011), and gambling (Brevers & Noël, 2013). Furthermore, our results are inconsistent with the only study that has examined the association between implicit affective attitudes and exercise dependence, which found that individuals who more strongly associated the concept of exercise with "importance" reported higher exercise dependence symptoms (Forrest et al., 2016). The discrepancy between our findings and those of Forrest et al. (2016) may perhaps be explained using different implicit association test content: whereas Forrest et al. (2016) assessed importance, our measure captured affective associations (i.e., the extent of automatically generated positive or negative emotional responses to PA). In summary, automatic reactions toward PA were not observed to be related to exercise dependence score, despite the robust link found between automatic reactions and dependence in several other contexts.

Theoretical implications

While there is a wealth of evidence to suggest that the incentive sensitisation theory of dependence largely explains how automatic processes to drug-related stimuli develop over time (Berridge & Robinson, 2003; Robinson & Berridge, 1993; Rooke et al., 2008), the evidence supporting this theory for explaining behavioural addictions is beginning to accumulate. A few studies of behavioural addictions, such as gambling or problematic pornography use, have shown that addicted individuals exhibit a neural signature of sensitisation with hyperreactivity of the mesolimbic dopamine system to addiction-related cues that is consistent with the signature commonly observed in substance dependence (Gola et al., 2017; Limbrick-Oldfield et al., 2017; Van Holst et al., 2018). To the best of our knowledge, no study has examined whether the same neural activity may underlie exercise addiction. However, based on our results, a more clearly established pattern of addiction may be necessary to investigate this issue, since scalar results on a measure of dependence do not appear to reach the threshold at which automatic reactions can be detected.

However, PA may have characteristics that distinguish it from other forms of addictive behaviour. For example, physical effort is inherent to PA and is processed as a cost and an aversive experience to be avoided (Cheval & Boisgontier, 2021; Cheval, Radel, et al., 2018; Maltagliati et al., 2022). Thus, from an evolutionary biological perspective (Bramble & Lieberman, 2004), one might wonder whether it is possible to develop a true dependence to behaviours that have an aversive value. Similarly, unlike gambling or pornography, PA behaviours are generally associated with delayed, not immediate, reward. For example, the intrinsic hedonic experience of exercise is triggered by the release of neurochemicals, such as endocannabinoids, but only after 30 minutes of moderate exercise (Raichlen et al., 2013). Therefore, it is possible that PA represents a specific behaviour in which the neuropsychological mechanisms underlying its addictive dimension may differ from those underlying behavioural addictions. Furthermore, unlike other addictive behaviours, many individuals do not engage in PA for its intrinsically rewarding qualities, but rather for long-term goals such as body image, health improvement, athletic performance, or social affiliation (Aaltonen et al., 2014; Ball et al., 2014; Molanorouzi et al., 2015). This further calls into question the addictive dimension of PA. Some authors suggest that exercise addiction may exist not only as a primary addiction, in which the reward is directly associated with exercise, but also, and more commonly, as a secondary addiction, in which exercise is used to cope with or compensate for other underlying problems (e.g., coping with emotional distress, weight control; Weinstein & Szabo, 2023). In such cases, the addictive aspects of PA are intertwined with primary addictions or underlying problems, as observed in eating disorders such as anorexia nervosa, bulimia nervosa, or other body image disorders (Weinstein & Szabo, 2023; Zou et al., 2022). In other words, the lack of robust evidence for a link between automatic processes and exercise dependence may also reflect the possibility that the psychological mechanisms at work in the development of exercise dependence are not underpinned by the development of automatic positive responses to exercise-related stimuli. Future research is needed to determine whether an idiosyncratic model of exercise dependence is needed or whether a general theory of dependence is sufficient to account for behavioural and neural observations (Dinardi et al., 2021).

Beyond these theoretical explanations, our different results can also be explained by methodological features.

Methodological explanations

First, a stronger association between automatic reactions and dependence score may be more likely at higher levels of dependence (Brevers et al., 2011). Accordingly, although our studies were designed to include only physically active individuals, we found that only a small number of participants exhibited high risk of exercise dependence according to the EDS-R (Hausenblas et al., 2017). Including a sample of participants with a higher risk of developing exercise dependence, such as Ironman athletes or ultramarathoners (Buck et al., 2018; Di Lodovico et al., 2019; Magee et al., 2016), seems to be a necessary condition for testing the hypothesised relationship between risk of exercise dependence and automatic reactions to PA. It is also emphasised that dependence is only one dimension of addiction, the other being compulsion (Szabo & Demetrovics, 2022). Addiction, which is more closely associated with automatic reactions to PA than dependence, involves both high dependence and high compulsion. Thus, it is possible that we missed the sought connection because the participants, despite exhibiting certain levels of dependence, were not compulsive in their exercise behaviour. Future studies assessing the risk of exercise dependence along measures of compulsion are recommended. Even better, selecting participants who score high on both measures of exercise dependence (or addiction) and compulsion should be followed up with interviews to ascertain addictive tendencies before examining their automatic reactions to PA.

In addition, in previous studies, the tasks involved personally relevant stimuli (Field et al., 2004; McGrath et al., 2018). In our studies, however, stimuli related to a specific exercise (i.e., a person doing fitness exercises) for the attention bias task, to the general concept of PA for the implicit affective attitudes task, and to a wide variety of physical activities (e.g., running, walking, cycling, swimming) for the approach-avoidance task. It has been shown that automatic reactions are more pronounced when the stimuli used in the task match participants' PA preferences (Limmeroth & Braun, 2022). Similarly, it has recently been suggested that the use of personally relevant stimuli may improve the effectiveness of interventions aimed at modifying automatic reactions toward health-related behaviours, including PA (Maltagliati et al., 2024; Wiers et al., 2020). In line with previous studies, personally relevant stimuli may need to be used to adequately capture automatic responses (Coppin & Pool, 2021; Pool et al., 2016; Stussi et al., 2019).

Finally, as explained above, behavioural outcomes (i.e., differences in reaction times) and eye-tracker data (i.e., differences in gaze patterns) may not provide a complete picture of the mechanisms underlying the automatic reaction toward PA behaviour (Cheval et al., 2021; Cheval & Boisgontier, 2021; Cheval, Radel, et al., 2018; Cheval, Tipura, et al., 2018; Parma et al., 2023). Accordingly, the use of neurophysiological methods, such as functional magnetic imaging or electroencephalography, seems highly relevant to complete the picture and advance the field.

Limitations and strengths

The present study has several limitations. The first set of limitations is based on the aforementioned methodological features – i.e., the relatively low levels of exercise dependence observed in our sample, which may have limited our ability to detect associations between exercise dependence and automatic responses to PA-related stimuli, the use of generic rather than personally relevant stimuli (Limmeroth & Braun, 2022; Maltagliati et al., 2024), and the reliance on behavioural outcomes and eye-tracker metrics that prevented us from examining the neural mechanisms underlying these automatic responses toward PA (Cheval, Radel, et al., 2018). In addition, although the scale used in this study may be treated in its continuous form, according to some theoretical perspectives, such as the interactional model of exercise dependence (Egorov & Szabo, 2013), exercise dependence is considered to emerge suddenly and therefore can hardly be measured on a scalar basis, but rather as presence versus absence and in-depth interviews may be necessary to identify addictive tendencies of clinical significance when addressing research questions akin to the current study. Future studies should seek to sample highly active individuals at higher risk of, or with documented, exercise addiction. Moreover, conducting this study online prevented us from controlling the conditions of data collection (e.g., quiet room, no distractions), which may have reduced the accuracy of the measures. However, studies have shown that online and laboratory settings can yield similar results (Francis et al., 2022; Germine et al., 2012; Gosling et al., 2004; Miller et al., 2018). Finally, usual levels of PA and of exercise dependence were assessed using self-report questionnaires, which may not accurately capture the actual levels of PA (Lee et al., 2011) and exercise dependence (Szabo et al., 2015). Assessing usual PA using device-based measures, such as accelerometers, or measuring exercise dependence using complementary methods, such as interviews, may provide more reliable and valid information.

Notwithstanding these limitations, our studies were some of the first to examine potential relationships between automatic responses and risk of exercise dependence. We examined all three discrete automatic reactions that have been thought to underlie dependence – i.e., attentional biases, implicit affective attitudes, and approach-avoidance tendencies – using not only behavioural outcomes (i.e., differences in reaction times), but also eye-tracking outcomes.

Conclusion

Automatic reactions to cues related to the addictive behaviour have been identified as a hallmark of dependence in a wide variety of contexts. This study has revealed some evidence that exercise dependence score was associated with one form of automatic reaction (i.e., behavioural attentional bias). However, the evidence remains insufficient to consider automatic reactions as a "signature" of exercise dependence. The lack of robust evidence may reflect the fact that exercise dependence differs from other forms of addiction and is not driven by the same automatic processes. Yet, it is important to emphasise that no definitive conclusions can be drawn given the limited extent of exercise dependence observed in our sample. Further research with individuals exhibiting higher risk of addiction, incorporating personally relevant stimuli, and using neurophysiological methods are warranted to better explore the mechanisms underlying exercise addiction.

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Credit authorship contribution statement

Anaïs Quossi: Conceptualization, Methodology, Investigation, Formal analysis, Data curation, Writing – original draft, Writing – review & editing. Layan Fessler: Conceptualization, Resources, Writing – original draft, Writing – review & editing. Silvio Maltagliati: Conceptualization, Resources, Writing – original draft, Writing – review & editing. Matthew W. Miller: Writing – review & editing.

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Disclosure statement

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