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Physically active individuals look for more: An eye-tracking study of attentional bias

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Abstract

Attentional capture by exercise-related stimuli is important for the regulation of physical activity. Attentional processing underlying this capture has been investigated with indirect behavioral measures based on reaction times. To investigate more direct measures of visual spatial attention toward physical activity (vs. inactivity) stimuli, we used eye-tracking and a visual dot probe task in 77 young adults with various level of physical activity. Reaction times to detect a dot appearing in the area previously occupied by a physical activity (vs. inactivity) stimulus were an indirect measure of attentional bias. The first picture gaze and viewing time were more direct measures of attentional orienting and attentional engagement, respectively. Pupil dilation was an indicator of arousal. Reaction times revealed a two-way interaction between the location of the dot and participants' usual level of physical activity. Only participants with a high level of physical activity more quickly detected a dot when it appeared in the area previously occupied by a physical activity stimulus. Eye-tracking results showed greater odds of first gazing at physical activity stimuli and for a longer time, and a greater decrease in pupil size when viewing physical activity stimuli when usual level of physical activity was moderate or high, but not low. The variance explained in the outcomes ranged from 13.9% (pupil dilation) to 40% (reaction times). Overall, as hypothesized, compared to less physically active participants, participants who were more physically active demonstrated indirect (reaction times) and direct (first gaze, viewing time) evidence of a more pronounced attentional bias toward physical activity. Physical activity stimuli biased attention, with a pronounced effect when the level of physical activity was higher. These findings suggest that physical activity stimuli are relevant to the current concerns of moderately and highly active individuals.

KEYWORDS

attentional capture, eye-tracking, physical activity, visual dot probe task

1 | INTRODUCTION

Most individuals are now aware of the negative health consequences of physical inactivity and have the intention to exercise (Canadian Fitness and Lifestyle Research Institute, 2018; Martin, Morrow, Jackson, & Dunn, 2000). Yet, despite their conscious motivation to be active, numerous individuals fail to exercise regularly. Only ~30% of the adult population worldwide regularly exercise (Guthold, Stevens, Riley, & Bull, 2018; WHO, 2010). Physical inactivity is estimated to be responsible of one death every 10 s worldwide (WHO, 2010). Until recently, the dominant approaches to exercise behavior were based on motivation theories focusing on how people reflect on their perceptions and attitudes (Brand & Cheval, 2019). Yet, meta-analyses examining the effectiveness of exercise-related interventions based on these reflective approaches have shown small effect sizes and high levels of unexplained variance (Chatzisarantis, Hagger, Biddle, Smith, & Wang, 2003; Hagger & Chatzisarantis, 2009). These results led to the development of theoretical perspectives highlighting the importance of the automatic evaluation of exercise-related stimuli in exercise-related decision-making and behavior (Brand & Ekkekakis, 2018; Cheval, Radel, et al., 2018; Conroy & Berry, 2017).

Multiple experimental studies support these perspectives by showing that exercise-related stimuli affect various types of automatic reactions including affective reactions (Bluemke, Brand, Schweizer, & Kahlert, 2010; Chevance, Caudroit, Romain, & Boiché, 2017; Conroy, Hyde, Doerksen, & Ribeiro, 2010; Rebar, Ram, & Conroy, 2015), approach tendencies (Cheval, Sarrazin, Isoard-Gautheur, Radel, & Friese, 2015, 2016; Cheval, Sarrazin, & Pelletier, 2014; Cheval, Sarrazin, Pelletier, & Friese, 2016; Hannan, Moffitt, Neumann, & Kemps, 2019), and attentional capture (Berry, 2006; Berry, Spence, & Stolp, 2011; Calitri, Lowe, Eves, & Bennett, 2009; Yun & Berry, 2018). Among these automatic reactions, attentional bias, defined as a person's selective attention toward certain types of stimuli while tending to overlook, ignore, or disregard others (Fadardi, Cox, & Rahmani, 2016), may be particularly important. For instance, a tendency to spontaneously allocate attention toward physical activity opportunities (e.g., a staircase) and to disengage from opportunities to minimize effort (e.g., an escalator) may help individuals effectively to regulate their physical activity behaviors.

Automatic processes, including attentional bias, can result of learned associations. For example, the repeated positive affective experiences associated with physical activity behaviors can result in an association between the hedonic effect (e.g., feeling well) and the behavior (e.g., running, walking). Once this learned association is consolidated in memory, a mere environmental input (e.g., seeing a person running or walking) can automatically guide attention and information processing, thereby favoring engagement in physical activity (Cheval, Radel, et al., 2018; Hofmann, Friese, & Wiers, 2008; Sheeran, Gollwitzer, & Bargh, 2013). In turn, engagement in the behavior should reinforce attentional bias over time. This theoretical perspective suggests a reciprocal association between attentional bias and physical activity: engaging in physical activity strengthens attentional bias because of the acquired relevance of activity-related stimuli, which in turn increases the interest in—and practice of—physical activity. Consequently, once an affective association with physical activity has been linked to its positive hedonic effects, attentional bias could be involved in both the development and maintenance of physical activity behaviors.

Several experimental paradigms have been developed to assess attentional biases such as the spatial cuing task, a free viewing task, visual search tasks, a modified version of the Stroop color-naming task, and the visual dot probe task (see Pool, Brosch, Delplanque, & Sander, 2016, for an overview of the measures). For example, in the modified version of the Stroop color-naming task (Field & Cox, 2008; Stroop, 1935), participants are asked to name the font color of words that related to the construct of interest (e.g., active or inactive-related words) and to neutral words. Slower reaction time in naming the font color of affectively laden words (e.g., physical activity) than neutral words indicates an attentional bias toward the affective words. In the modified version of the visual dot probe task (MacLeod, Mathews, & Tata, 1986), two words or images are presented simultaneously on a screen. Then, one is replaced by a dot. The participant is instructed to indicate as quickly as possible where the dot appears by pressing the left or right response key. Some of the stimuli are related to the construct of interest and others are "neutral." A shorter reaction time to detect the dot when it appears in the area previously occupied by the affectively laden stimulus is thought to reflect an attentional bias toward this type of stimulus. It has been suggested that such paradigms typically reveal that attention is biased toward stimuli that are particularly relevant to the current concerns of the participants (Pool et al., 2016).

However, few studies have assessed attentional bias toward physical activity and sedentary behaviors (Berry, 2006; Berry et al., 2011; Calitri et al., 2009; Oliver & Kemps, 2018; Yun & Berry, 2018). Using a Stroop color-naming task with words related to physical activity (e.g., energetic, vigorous, muscle), control (e.g., synthetic, suburban, varied), or sedentary behavior (e.g., unmotivated, lethargic, unfit), Berry (2006) showed that exerciser schematics (i.e., people who identify strongly as exercisers) are biased toward physical activity stimuli, whereas non-exerciser schematics are biased toward sedentary stimuli. Using a visual dot probe task based on pairs of words (physical activity vs. neutral words), Calitri et al. (2009) showed that self-reported physical activity during the past 7 days was positively correlated with attentional bias toward physical activity. A second study using a visual dot probe task based on pairs of pictures (physical activity vs. neutral images) showed that men demonstrated an attentional bias toward physical activity, regardless of their usual physical activity level, whereas only active women showed this attentional bias toward physical activity (Berry et al., 2011). Another study drawing on the experimental paradigm of Berry et al. (2011) did not observe an association between attentional bias toward physical activity images and past week daily steps (Oliver & Kemps, 2018). Finally, Yun and Berry (2018) conducted a study aiming to demonstrate that incorporating measures of automatic processes can provide additional information to improve the evaluation of a community-wide physical activity program. Using a visual dot probe task based on pictures related to the program, they showed that an attentional bias toward these images was associated with greater self-reported physical activity. Overall, although some studies are inconclusive, this literature suggests an association between attentional bias and physical activity behaviors. Yet, although the visual dot probe task is thought to reflect a more direct measure of the attentional bias toward a specific type of stimulus than the Stroop color-naming task, attentional bias is still inferred from difference in reaction times and not directly assessed. It has been suggested that more direct measures of attentional bias may be more reliable than the indirect ones that suffer from low internal and test–retest reliability (Pennington, Qureshi, Monk, Greenwood, & Heim, 2019).

To the best of our knowledge, only one study has directly investigated attentional bias toward physical activity using eye-tracking (Giel et al., 2013). This study used a picture viewing task in which participants were asked to freely explore pairs of pictures presented on the screen, one related to physically activity (e.g., a young female athlete exercising) and the other one related to physically inactivity (e.g., a young female athlete in a passive situation). Anorexia nervosa patients and athletes showed higher attentional engagement (i.e., longer gaze) toward physical activity pictures than non-athletes. These findings suggest that physical activity behaviors are particularly relevant to the current concerns of active and hyperactive (i.e., anorexia nervosa patients) individuals. However, this study was designed to unravel the mechanisms underlying hyperactivity in women suffering from anorexia, not to examine these mechanisms in healthy individuals.

Here, the objective was to extend current insights in the associations between the usual level of physical activity and attentional bias toward physical activity versus inactivity stimuli. To this end, we combined indirect and more direct indicators of attentional bias to examine how the usual level of physical activity influences visual processing. We used an eye tracker and a visual dot probe task depicting physical activity versus inactivity stimuli to assess attentional processing in individuals with low to high levels of usual physical activity. We used differences in reaction times to detect the dot when it appeared in the area previously occupied by a physical activity (vs. inactivity) stimulus as a behavioral indicator of an attentional bias toward physical activity. We used first gaze location (attentional orienting) and gaze duration (attentional engagement) as indicators of visual spatial attention. Additionally, we recorded pupil responses when participants looked at physical activity (vs. inactivity) stimuli. Pupil dilatation was used as an indicator of the value representation of the stimulus as pupil dilatation is influenced by value and arousal (Pauli et al., 2015; Pool, Pauli, Kress, & O'Doherty, 2019; Prévost, McNamee, Jessup, Bossaerts, & O'Doherty, 2013; Seymour, Daw, Dayan, Singer, & Dolan, 2007).

We hypothesized that individuals with higher levels of usual physical activity demonstrate both indirect (behavioral outcome) and more direct (eye-tracking outcomes) evidence of higher attentional capture by physical activity (vs. inactivity) stimuli, when compared to individuals with lower levels of usual physical activity. Therefore, we excepted that the more active participants, as compared to the less active participants, are faster to detect the dot when appearing in the area previously occupied by a physical activity stimulus (*H1*), initially direct their gaze toward physical activity stimuli (*H2*), gaze at physical activity stimuli for a longer time (*H3*), and demonstrate greater pupil dilatation when looking at physical activity stimuli (*H4*). Finally, to examine the associations between indirect and direct measures of attentional processing, we explored whether the more direct indicators of attentional processing (i.e., first gaze and gaze duration) and arousal (i.e., pupil dilation) could predict the behavioral performance (reaction times) in the visual dot probe task.

2 | METHOD

2.1 | Participants and procedures

Participants were recruited through posters, directly at the university library, or from the Psychology Department Research Subject Pool, which offers course credit to participants. To be included in the study, participants had to be willing to participate in a one-hour laboratory session on the topic of physical activity. Participants with a history of psychiatric, neurological, or severe mental disorders, or taking psychotropic medication or illicit drugs at the time of the study were excluded. Eighty-four students were recruited.

All participants were seated in an experimental cubicle in front of a computer and provided written informed consent prior to participation. The experimental cubicle was situated in a basement unexposed to natural light. The main light of the room and the light of the cubicle were turned on by a research assistant during the experiment, thereby ensuring standardized light circumstances. Participants were asked to complete a questionnaire assessing their usual level of physical activity and their intention to be active two items: "I intend to (I am determined to) partake in at least 30 min of moderate-to-intense physical activity per day, most days of the week during my free time or as a way to get from one place to another." They also provided demographics information (age, sex, height, weight). Before doing the visual dot probe task, participants completed a first reaction-time task (either a decision lexical task or a go-no go task), which lasted 8–10 min (These data are not used in the current study). Immediately afterward, participants filled out a short questionnaire assessing some potential confounding variables (e.g., hunger, thirst, physical activity during the previous day and the current day, sleep pattern, caffeine, and cigarette consumption). The University of Geneva Ethics committee approved this research and informed consent process.

2.2 | Measures

2.2.1 | Visual dot probe task

A visual dot probe task was used to measure the attentional bias toward physical activity (vs. inactivity) stimuli using eye-tracking (MacLeod et al., 1986). Each trial began with a fixation cross in the center of the screen with a white background. Trials initiated when the participants looked at this fixation cross randomly for between 800 and 1,100 ms. Two pictures (one related to physical activity and one related physical inactivity) were subsequently presented on the left and right side of the screen randomly for 4,000 to 4,500 ms. A black dot was then presented either on the left or right side of the fixation cross. Participants were requested to press the "S" key when the dot was displayed on the left and the "L" key when it was displayed on the right, with the left and right hand, respectively. The dot remained on the screen until the participant's answer. Then, the next trial started (Figure 1).

After positioning the participant, the research assistant read the following instructions:

> *You will be completing a reaction time task in which you will be asked to detect, as quickly as possible, on which side of the screen a black dot will appear. Each trial will begin with the presentation of two images. One on the left side of the screen and the other on the right side of the screen. Next, the two pictures will disappear from the screen, and one of them will be replaced by a black dot. Your task will be to indicate, as quickly as possible, on which side of the screen the dot appeared. Crucially, the side the dot appears is totally random and is not linked to the pictures presented on the screen. As such, it is not possible for you to anticipate the side where the dot appears. If the dot appears on the left, you press the 'S' key on the keyboard. If the dot appears on the right, you press the 'L' key on the keyboard. We ask you to place your left index on the 'S' key and your right index on the 'L' key.*

The task consisted of six training trials and 80 experimental trials in which the dot appeared with an equal frequency in the area previously occupied by an active and inactive stimulus, and the position of the dot and the type of stimulus were counterbalanced with respect to appearing on the left and right side of the screen. Consistent with previous studies, reaction times (i.e., the time elapsed between the appearance of the dot on the screen and the participant's response) to detect a dot when it replaced a physical activity (vs. inactivity) stimulus was used as an indirect indicator of attentional bias. First gaze location (i.e., attentional orienting), gaze duration (i.e., attentional engagement) were used more direct indicators of attentional processing, and pupil dilatation as an indicator of arousal.

We used the same stimuli as in Kullmann et al. (2014). Specifically, five pairs of images displaying a physically active versus physically inactive woman were selected. The advantage of these stimuli is that images are closely matched for color, brightness, visual complexity, valence, and arousal. The only element that critically varies is the level of energy

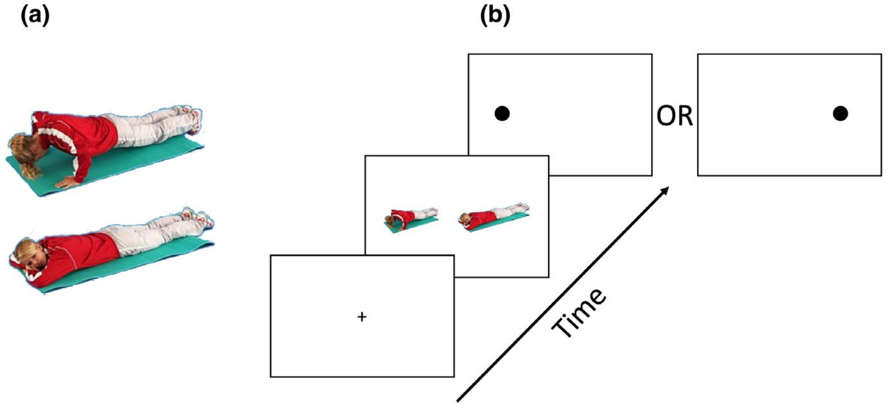

FIGURE 1 Visual dot probe task. (a) Stimuli. (b) Procedure. Trials started with an 800 to 1,100 ms fixation of the cross. Then, stimuli depicting physical activity and inactivity appeared for 4,000 to 4,500 ms. Then, a black dot replaced either the physical activity or inactivity stimulus. The experiment consisted of one block of 80 trials. Participants were instructed to detect the side where the dot appeared, as quickly as possible. In half of the trials, the dot appeared on the side of the active stimuli. In the other half, the dot appeared on the side of the inactive stimuli

expenditure of the displayed individual. The visual dot probe task is available on the Zenodo open-access repository (https://doi.org/10.5281/zenodo.3371190).

2.2.2 | Usual level of physical activity

The usual level of physical activity was measured using an adapted version of the International Physical Activity Questionnaire (IPAQ; Craig et al., 2003) assessing moderate-to-vigorous intensity activities undertaken during leisure time during a usual week.

2.3 | Statistical analysis

Reaction times, gaze location, gaze duration, and pupil dilation were analyzed using mixed effects models to account for the cross-random effects (participants and stimuli) and to decrease the risk of type-I error (Boisgontier & Cheval, 2016; Judd, Westfall, & Kenny, 2012). We built a linear mixed effects model using the lme4 and lmerTest packages in R and specified both participants and stimuli as random factors (Bates, Mächler, Bolker, & Walker, 2015; Kuznetsova et al., 2016; R Core Team, 2017). To reduce convergence errors, each model was first 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 then, the L-BFGS-B optimizer (See Frossard & Renaud, 2019, for similar procedure). If all optimizers failed, we step-by-step reduced the complexity of the random structure until we obtained a solution without convergence issues (see Table 2 for the final random structure). An estimate of the effect size was reported using the conditional pseudo R^2 computed using the MuMIn package (Barton, 2018). Statistical assumptions associated with MEM (normality of the residuals, linearity, multicollinearity, and undue influence) were checked and met for all models.

2.4 | Behavioral outcome

Incorrect responses (0.9%), responses below 200 ms (none), and responses above 1,500 ms (0.4%) were excluded. Reaction times were log-transformed to normalize their distribution (models using reaction times in their raw metric revealed the same results as presented below). Faster reaction times to detect a dot when it appeared in the area previously occupied by an active (vs. inactive) stimulus was used as a behavioral indicator of attentional bias toward physical activity stimuli. The within factor dot (two modalities: appeared in the area previously occupied by a physical activity vs. inactivity stimulus), the usual level of physical activity, and their interaction were included as fixed effects.

2.5 | Eye-tracking outcomes

2.5.1 | First gaze

The association between the usual level of physical activity and the odds of first gazing at physical activity (vs. inactivity) stimuli was analyzed using a logistic mixed effects model. For each trial, a first gaze toward physical activity stimuli was coded 1, whereas a first gaze toward physical inactivity stimuli was coded 0. Usual level of physical activity was included as a fixed effect.

2.5.2 | Gaze duration

The association between the usual level of physical activity and the relative viewing time toward physical activity (vs. inactivity) stimuli was analyzed using a linear mixed effects model.

2.5.3 | Pupil dilation

For each trial, the difference in the maximum pupil size when viewing physical activity (vs. inactivity) stimuli was used as an outcome. Based on the data distribution, pupil size below 2 mm and above 4.5 mm were excluded. Pupil size differences larger that |1| mm between physical activity and inactivity stimuli were also excluded. We used the same fixed and random structure as the one used for first gaze and gaze duration.

As previous studies suggested that attentional processing toward physical activity stimuli may differ between gender (Berry et al., 2011), we explored whether gender moderated the observed effects.

2.6 | Predicting behavioral performance with eye-tracking outcomes

We used a series of mixed effects models to examine whether the eye-tracking outcomes predicted reaction times to detect the dot when it appeared in the area previously occupied by a physical activity (vs. inactivity) stimulus, separately. The models included one eye-tracking index at a time to predict the reaction times. Finally, we explored whether gender and the usual level of physical activity influenced these associations by adding interaction terms in the models.

3 | RESULTS

3.1 | Descriptive results

Table 1 shows the characteristics of the participants by usual level of physical activity. For descriptive purposes, participants were categorized as either reporting reaching the 150 min per week of moderate-to-vigorous physical activity guidelines versus not reaching this threshold. A total of 84 students were recruited, but seven did not complete the physical activity questionnaire. The final sample size included 77 participants (52 women and 25 men; 34 active and 43 inactive participants; mean age 21.7 ± 3.8 years; mean body mass index 21.5 ± 3.1 kg/m^2), with a moderately high intention to be active (mean intention, 7.6 ± 2.0, on a scale ranging from 1 to 10). The more active participants had a higher intention to be active, a higher number of first look toward physical activity (vs. inactivity) stimuli, and a longer relative viewing time to physical activity (vs. inactivity) stimuli than less active participants. Age, gender, and body mass index were similar across more and less active participants. Overall, the usual level of moderate to vigorous physical activity was 199.3 min per week (±261.4 min).

3.2 | Reaction times

Results revealed a two-way interaction between the location of the dot (appeared in the area previously occupied by a physical activity vs. inactivity stimulus) and participants' usual level of physical activity, suggesting that the effect of

TABLE 1 Participant's characteristics by usual level of physical activity

	Physically inactive (n = 43)		Physically active (n = 34)		
		SD		*SD*	*p*
Age, (years) (mean)	21.6	3.2	21.9	3.0	.776
Gender (number; % of women)	29	67%	23	68%	.999
BMI (kg/m^2) (mean)	21.3	2.5	21.8	3.8	.550
Intention to be active (Likert scale; 1–10) (mean)	7.1	2.1	8.3	1.7	.006
Usual level of physical activity (min) (mean)	57	47	378	310	<.001
Mean reaction time to detect a dot (ms)					
On the physically active stimuli side (mean)	458.9	88.1	443.6	59.0	.367
On the inactive stimuli side (mean)	453.5	80.7	455.3	64.2	.913
Relative reaction time (mean)	5.4	23.3	−11.7	29.9	.008
First gaze (probability 0 to 1)					
On the physically active (vs. inactive) inactive stimuli (probability)	.54	.07	.59	.09	.020
Gaze duration (ms)					
On the physically active stimuli (mean)	1041.8	650.6	1346.9	793.5	.075
On the physically inactive stimuli (mean)	851.8	503.7	902.2	501.8	.664
On the fixation cross	1871.0	1262.7	1790.4	1344.2	.789
On the physically active (vs. inactive) stimuli (mean)	444.7	554.6	190	360	.024
Relative viewing time (%)	7%	13%	18%	19%	.005
Pupil dilation (mm)					
When viewing physically active stimuli (mean)	2.88	0.28	2.77	0.24	.071
When viewing physically inactive stimuli (mean)	2.89	0.28	2.79	0.25	.104
When viewing the fixation cross (mean)	2.91	0.27	2.82	0.24	.129
Relative pupil dilation (mean)	−0.02	0.03	−0.04	0.10	.263

Notes: Relative reaction time is the averaged reaction time difference to detect a dot when it appeared in the area previously occupied by a physical activity compared to a physical inactivity stimulus. First gaze is the probability to first gaze at physical activity compared to physical inactivity stimuli. Zero equals a likelihood to first gaze at physical inactivity stimuli in all the trials, whereas 1 equals a likelihood to first gaze at physical activity stimuli in all the trials. Relative viewing is the averaged percentage difference in the time spent gazing at physical activity compared to physical inactivity stimuli. A higher score indicated a longer viewing time of physical activity stimuli. Relative pupil dilation is the averaged difference in pupil size when viewing physical activity compared to physical inactivity stimuli. A higher score indicated a larger pupil size when looking at physical activity stimuli.

Abbreviations: BMI, body mass index; kg/m^2, kilograms/meters^2; mm, millimeters; ms, milliseconds; *SD*, standard deviation.

dot location on reaction time varied as a function of the usual level of physical activity ($b = -.02$, 95% Confidence Interval [*95CI*] = −.03 to −.01, $p = .002$) (Table 2). As expected (*H1*), simple effect tests showed that when the usual level of physical activity was low (*−1SD*) or moderate (mean), participants were not faster to detect a dot appearing in the area previously occupied by a physical activity (vs. inactivity) stimulus ($b = .01$, *95CI* = −.01 to .03, $p = .167$ and $b = -.06$, *95CI* = −.04 to .03, $p = .224$, for low and moderate usual levels of physical activity, respectively). By contrast, when the usual level of physical activity was high (*+1SD*), participants were faster to detect a dot when it appeared in the area previously occupied by a physical activity (vs. inactivity) stimulus ($b = -.025$, *95CI* = −.04 to −.01, $p = .003$) (Figure 2). The variables under consideration explained 40% of the variance in the reaction times. Gender did not influence the effects ($p = .235$). In other words, consistent with our first hypothesis, results revealed that, compared to less active participants, more active participants exhibited a greater attentional bias toward physical activity as they were quicker to detect a dot that replaced physical activity stimuli than nonphysical activity stimuli.

3.3 | Eye-tracking

3.3.1 | First gaze

Results showed an effect of the usual level of physical activity on the spatial location of the first gaze that followed the location of the fixation cross (Table 2). As expected (*H2*), the odds of gazing first at physical activity (vs. inactivity) stimuli increased as the usual level of physical activity increased (odds ratio [*OR*] = 1.14, *95CI* = 1.03 to 1.26, $p = .012$). Simple effect tests showed that when the usual level of physical activity was high (*+1SD*) or moderate (mean), the odds of gazing first at physical activity stimuli were higher than the odds of gazing first at physical inactivity stimuli (*OR* = 1.61, *95CI* = 1.27 to 2.03, $p < .001$ and *OR* = 1.42, *95CI* = 1.15 to 1.74, $p = .001$, for high and moderate usual levels of physical activity, respectively). By contrast, when the usual level of physical activity was low (*−1SD*) only a trend was observed (*OR* = 1.24, *95CI* = .99 to 1.58, $p = .065$) (Figure 3 upper panel). The variables under consideration explained 28.1% of the variance in the attentional orienting. Gender did not influence the effects ($p = .532$). Consequently, consistent

TABLE 2 Results of the linear mixed models predicting the reaction times (log) required to go toward physical activity and inactivity stimuli

	Model: Response time (log) to detect the dot		**Model: Probability to first gaze at active versus inactive stimuli**		**Model: Relative viewing time toward active versus inactive stimuli**		**Model: Relative pupil size toward active versus inactive stimuli**	
	***b* (*CI*)**	***p***	***OR* (*CI*)**	***p***	***b* (*CI*)**	***p***	***b* (*CI*)**	***p***
Variables								
Fixed effects								
Intercept	6.09 (6.06;6.12)	<.001	1.42 (1.03;1.63)	.001	12.4 (5.5;19.2)	.004	−.016 (−.02; .01)	.001
Dot side (ref. on inactive stimuli)	−.01 (−.02; .01)	.224						
Usual level of PA	−.01 (−.04; .03)	.732	1.14 (1.03;1.26)	.012	7.8 (4.7;10.9)	.01	−.01 (−.01;− .002)	.008
Dot side × usual level of PA	−.02 (−.03;− .01)	.002						
Random effects								
Participants								
Intercept	2.1×10^{-2}		70.7	9.4×10^{-5}				
Dot side	7.5×10^{-4}							
Stimuli								
Intercept	1.5×10^{-5}	.85	96.4	5.9×10^{-5}				
Corr. (Intercept, dot side)	−0.01							
Participants by dot side								
Intercept		1.18	725.5	1.9×10^{-3}				
Residual	3.3×10^{-2}		2373.7	1.3×10^{-2}				
R^2	.400	.281	.29	.139				

Abbreviations: *CI*, 95% confidence interval; Corr., correlation; *OR*, odds ratio.

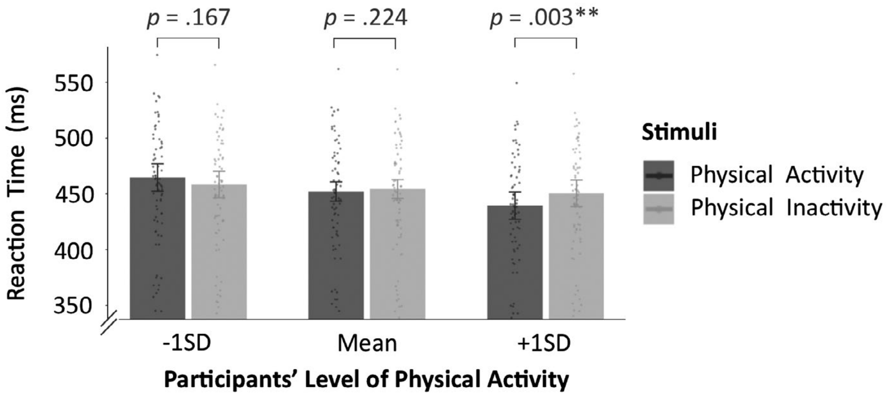

FIGURE 2 Reaction times. Reaction times to detect the dot when it appeared in the areas previously occupied by physical activity (vs. inactivity) stimuli as a function of participants' usual level of physical activity. Reaction times in log were back transformed into milliseconds

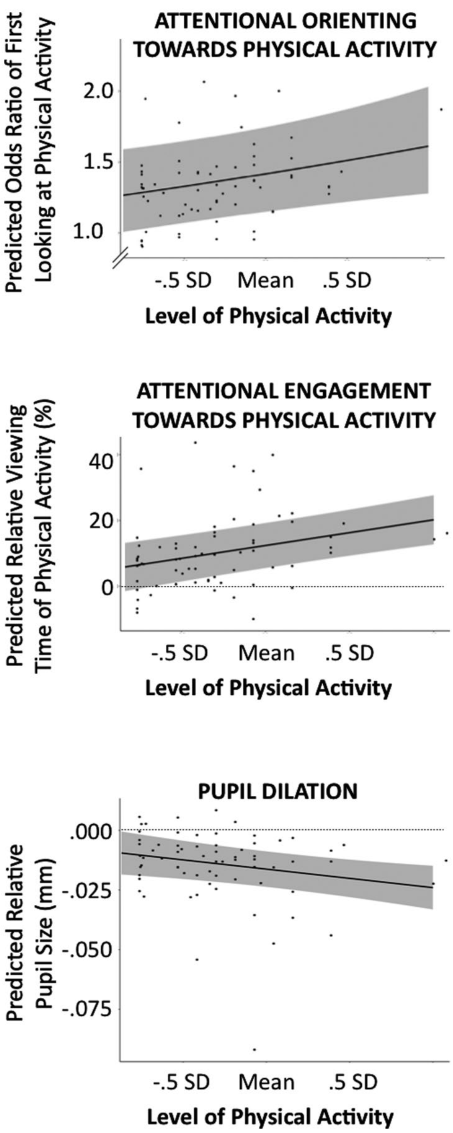

FIGURE 3 Eye-tracking outcomes. Upper panel. Attentional orienting. The odds ratio of first gazing at physical activity (vs. inactivity) stimuli as a function of the level of physical activity. Middle Panel. Attentional engagement. The relative percentage of time spent gazing at physical activity (vs. inactivity) stimuli as a function of the level of physical activity. Lower panel. Pupil dilation. The relative pupil size when gazing at physical activity (versus. inactivity) stimuli as a function of the level of physical activity. Grey area = 95% confidence interval

with our second hypothesis, results revealed that, compared to less active participants, more active participants demonstrated an attentional bias toward physical activity as they were more likely to first look at physical activity stimuli than at nonphysical activity stimuli.

3.3.2 | Gaze duration

Results showed an effect of the usual level of physical activity on the time spent looking at the physically active stimuli (Table 2). As expected (*H3*), the viewing time of physical activity (vs. inactivity) stimuli increased as the usual level of physical activity increased ($b = 7.8$, *95CI* = 4.8 to 10.9, $p < .001$). Specifically, when the usual level of physical activity was high (+*1SD*) or moderate (mean), participants stared at the physical activity stimuli 20.2% (*95CI* = 12.7 to 27.7, $p < .001$) and 12.4% (*95CI* = 5.5 to 19.2, $p = .004$) longer than at the physical inactivity stimuli, respectively. By contrast, when the usual level of physical activity was low (−*1SD*), no differences were observed ($b = 4.6\%$, *95CI* = −3.0 to 12.1, $p = .253$) (Figure 3 middle panel). The variables under consideration explained 28.8% of the variance in the attentional processing. Gender did not influence the effects ($p = .427$). In other words, consistent with our third hypothesis, results revealed that, compared to less active participants, more active participants demonstrated an attentional bias toward physical activity as they spent more time looking at physical activity stimuli than at nonphysical activity stimuli.

3.3.3 | Pupil dilation

Results showed an effect of the usual level of physical activity on pupil dilatation when viewing physical activity stimuli (Table 2). The pupil size decrease observed when participants viewed physically active (vs. inactive) stimuli was more pronounced as the usual level of physical activity increased ($b = -.1$, *95CI* = −.01 to −.002, $p = .008$). Specifically, when the usual level of physical activity was high (+*1SD*) or moderate (mean), pupil size decreased by −.024 mm (*95CI* = −.033 to −.015, $p < .001$) and −.016 mm (*95CI* = −.024 to −.008, p = .001) when viewing physical activity (vs. inactivity) stimuli, respectively. By contrast, when the usual level of physical activity was low (−*1SD*), we only observed a trend ($b = -.009$, *95CI* = −.018 to.001, $p = .090$) (Figure 3 lower panel). The variables under consideration explained 13.9% of the variance in pupil dilation. Gender did not influence the effects ($p = .267$). Thus, contrary to our fourth hypothesis, results showed that, compared to less active participants, more active participants did not demonstrate greater arousal, but rather lower arousal—a greater decrease in pupil size.

3.4 | Predicting behavioral performance with eye-tracking outcomes

3.4.1 | Dot appearing in the area previously occupied by a physical activity stimulus

In the models including a single eye-tracking index at a time, results showed that a higher percentage of viewing time of physical activity (vs. inactivity) stimuli predicted shorter reaction times to detect the dot ($b = -2.4 \times 10^{-4}$, *95CI* = -3.8×10^{-4} to -1.1×10^{-4}, $p < .001$), whereas neither first gaze ($b = 1.7 \times 10^{-3}$, *95CI* = −.013 to .017, $p = .819$), nor pupil dilation did ($b = 1.9 \times 10^{-2}$, *95CI* = −.05 to .09, $p = .584$). The variables under consideration explained 36.3% of the variance in the reaction times. These effects did not vary as a function of the usual level of physical activity or gender.

3.4.2 | Dot appearing in the area previously occupied by an inactive stimulus

In the models including a single eye-tracking index at a time, results showed that pupil dilatation when staring at physical activity (vs. inactivity) stimuli predicted longer reaction times (although $p = .067$; $b = 6.2 \times 10^{-2}$, *95CI* = −.004 to .130), whereas neither viewing time ($b = -5. \times 10^{-5}$, *95CI* = -1.8×10^{-4} to 8.9×10^{-5}, $p = .442$) nor attentional orienting did ($b = 9.9 \times 10^{-4}$, *95CI* = −.014 to .016, $p = .896$). Gender modified the effect of pupil dilation ($b = -.15$, *95CI* = −.30 to −.004, $p = .044$), with an effect found in women ($b = .12$, *95CI* = .04 to .20, $p = .005$), but not in men ($b = -.03$, *95CI* = −.15 to .08, $p = .604$). The variables under consideration explained 36.3% of the variance in the reaction times.

4 | DISCUSSION

This study examined attentional processing toward physical activity and inactivity stimuli in a sample of healthy individuals with low to high self-reported usual levels of physical activity. Our results provide eye-tracking-based empirical evidence that physical activity stimuli bias attention, especially in individuals with higher levels of physical activity. Hence, our study lends support to recent theories in exercise psychology stressing that automatic reactions toward exercise-related stimuli are involved in the regulation of physical activity behaviors (Brand & Ekkekakis, 2018; Cheval, Radel, et al., 2018; Conroy & Berry, 2017).

As hypothesized (*H1*), behavioral results revealed an interaction effect between dot location and the usual level of physical activity. Participants were faster at detecting a dot when it appeared in the area previously occupied by a physical activity (vs. inactivity) stimulus but only when the usual level of physical activity was high, thereby suggesting that the more active participants, but not the less active ones, demonstrated an attentional bias toward physical activity. Overall, these findings are in line with previous results showing evidence of an attentional bias toward active stimuli in active individuals using differences in reaction times (Berry, 2006; Berry et al., 2011; Calitri et al., 2009; Yun & Berry, 2018), although some differences can be noted. For example, Berry et al. (2011) showed that all men, regardless of their usual physical activity level, demonstrated such bias toward active stimuli, whereas only active women showed evidence of this bias. One possible explanation of this discrepancy lies in the characteristics of the visual dot probe task. Specifically, the control-related images used in Berry et al. (2011) included objects that could be associated with specific affective contents (e.g., remote control, baby, vacuum cleaner, beer bottle), which may be gender dependent. By contrast, our pairs of physical activity and inactivity images were selected to only differ in terms of energy expenditure suggested by the pictures, with the person represented being the same in all the images (see https://doi.org/10.5281/zenodo.3371190). Yet, our results are consistent with other studies showing an association between attentional bias toward physical activity, irrespective of gender (Berry, 2006; Calitri et al., 2009; Yun & Berry, 2018).

As expected (*H2* and *H3*), participants showed greater odds of gazing first at physical activity stimuli and to stare longer at them when the usual level of physical activity was higher. When the usual level of physical activity was high or moderate, participants showed greater odds of gazing first at and to view longer physical activity (vs. inactivity) stimuli, whereas these effects were not significant when the usual level of physical activity was low. These findings showed that active participants are biased toward physical activity, thereby suggesting that indices associated with physical activity could be particularly relevant to the current concerns of active individuals (Pool et al., 2016).

Attentional bias to positive stimuli is thought to be the result of learned associations that serve the purpose of making rewarding behaviors more efficiently and spontaneously initiated (Rebar, 2017). Hence, this lends support for the suggestion that physical activity could be perceived as rewarding (Dietrich & McDaniel, 2004; Olsen, 2011; Raichlen, Foster, Gerdeman, Seillier, & Giuffrida, 2012), especially in hyperactive and highly active individuals (Giel et al., 2013). These reward-learning processes play a key role in the development and maintenance of addiction (Hyman & Malenka, 2001), with a behavior transitioning from a voluntary mode of regulation to an automatic one, in which cues linked to the addictive behavior increase in incentive salience (Robinson & Berridge, 1993; Wiers et al., 2014). For example, attentional captures are observed in smokers (Field & Cox, 2008), drinkers (Schoenmakers et al., 2010), or in people with eating disorders (Dobson & Dozois, 2004; Papies, Stroebe, & Aarts, 2008). Consequently, attentional bias toward physical activity stimuli could potentially, when populations with a disorder are tested, be considered as an index of the level of disorder in the processing of such rewarding information (Giel et al., 2013; Wiers & Stacy, 2006). Future research aiming to disentangle whether attentional bias, as well as other automatic processes, are related to healthy or unhealthy modes of regulation of physical activity are needed. These will further improve our understanding of the role of automatic cognition in the development and maintenance of healthy and unhealthy physical activity patterns (Cheval et al., 2020).

To the best of our knowledge, only one other study used eye-tracking to assess attentional processing of physical activity stimuli (Giel et al., 2013). In this study, results showed that people with anorexia nervosa and athletes who competitively practiced endurance sports for at least 5 hr per week, as well as nonathletes, first orient their attention to physical activity (vs. inactivity) stimuli. Although this study did not find group differences in attentional orienting, both anorexia nervosa patients and athletes demonstrated higher attentional engagement (i.e., longer gaze) toward physical activity (vs. inactivity) stimuli, when compared with nonathletes. Overall, our findings are consistent with this study but showed a difference in the direct measure of attentional processing in a healthy population.

Contrary to our hypothesis (*H4*), participants showed a greater decrease in pupil size when viewing physical activity (vs. inactivity) stimuli when the usual level of physical activity was higher. As for the other eye-tracking outcomes, results showed that this effect was only observed when the usual level of physical activity was high or moderate, but not low. These results suggest that physical activity stimuli are associated with less arousal than physical inactivity stimuli, especially in physically active individuals. Yet, it should be noted that the association between the level of physical activity and change in pupil size was very small (0.02 mm) and could hardly be distinguished from simple measurement error. Therefore, it seems reasonable to avoid overinterpreting this result.

Results showed that greater attentional engagement toward physical activity stimuli was associated with a faster detection of a dot when it appeared in the area previously occupied by an active stimulus. This result confirms that the indirect measure of attentional bias in the visual dot probe task (i.e., difference in reaction times) reflects differences in attentional engagement. This finding suggests that attentional bias as measured by a visual dot probe task with a relatively long presentation of the stimuli may accurately reflect attentional engagement (or difficulty of disengagement) but not attentional orienting. Regarding the reaction time to detect the dot when it appeared in the area previously occupied by a physical inactivity stimulus, higher pupil dilation was associated with slower reaction times in women. This result may suggest that higher arousal to physical activity (vs. inactivity) stimuli disrupted the behavioral performance when women had to detect the dot appearing after a physical inactivity stimulus. Yet, this result should be interpreted with caution (see above the discussion on pupil size interpretation).

Among the strengths of the study are the use of eye-tracking technology in a visual dot probe task allowing the measurement of both direct and indirect indicators of attentional processing toward physical activity (vs. inactivity) stimuli, and offering a broad perspective on attentional bias (first gaze and gaze duration) and arousal (pupil dilation); the first comparison of a normal, non-pathological, sample of physically active and inactive individuals; and the use of statistical analyses suited to examine repeated measures data involving cross-random factors (i.e., participants and stimuli). However, this study also has some limitations. First, physical activity was measured using self-report. Other assessment techniques (e.g., accelerometry) could more accurately assess participants' usual level of physical activity. Second, because our study was based on correlational data, it was not possible to assess the directionality of the associations. Future longitudinal studies could clarify the nature of the relationship between attentional bias and physical activity. Likewise, experimental studies designed to directly modify attentional bias, such as attention bias modification treatment (MacLeod, Rutherford, Campbell, Ebsworthy, & Holker, 2002), could investigate the causal effect of attentional bias on physical activity. Third, the visual dot probe task did not involve "neutral/irrelevant" stimuli. As such, the faster reaction time to detect a dot when it appeared in the area previously occupied by a physical activity (vs. inactivity) stimulus could also reflect a slower reaction to detect inactive stimuli. Moreover, as previous studies showed that physically inactive opportunities act as temptations threatening the achievement of physical activity goals (Cheval, Sarrazin, Boisgontier, & Radel, 2017; Cheval, Tipura, et al., 2018), these opportunities could also bias attention. As such, difference between physical activity and inactivity stimuli could be smaller than the difference with stimuli irrelevant to the current participants concerns. Future studies could examine whether both active and inactive stimuli attract attention, when compared with nonrelevant stimuli. Fourth, the pictures used in the current study displayed a woman. Therefore, we cannot exclude the possibility that these pictures were differentially processed by men and women. Developing a set of pictures displaying both men and women will be important in future research aiming to test any effect of gender. Fifth, although the light circumstances were standardized and should, therefore, secure the validity of the results obtained for pupil dilation, we did not formally assess luminance values. As pupil size is extremely sensitive to light changes, the measure of the luminance values across the experiment (and its use as a covariate in the model) could improve the accuracy of the estimates by adjusting for the undue variance related to this luminance. Sixth, although the visual dot probe task is thought to reflect a measure of the attentional bias toward a specific type of stimulus, other studies suggest that this task, as often observed in implicit measures (Gawronski & De Houwer, 2014), lacks validity and reliability (Rodebaugh et al., 2016; Schmukle, 2005). Consequently, the results arising from the task, especially the behavioral ones, should be evaluated in the light of its limitations. Replications of our results using other tasks would be an interesting addition to the literature. Finally, our study assessed attentional bias toward physical activity while participants had remained seated for a non-negligible amount of time (~20 min). This may have artificially biased the results toward a lower attraction toward physical inactivity in line with the outcome devaluation phenomenon (Pool et al., 2019). Future studies should experimentally manipulate the situational factors likely to change the attractive value of physical activity and inactivity behaviors (Cheval, Boisgontier, Bacelar, Feiss, & Miller, 2019; Cheval, Radel, et al., 2018).

In conclusion, compared with less active participants, more active participants demonstrate greater indirect (reaction times) and more direct (first gaze, viewing time) evidence of an attentional bias toward stimuli that depict physical activity. This bias suggests that stimuli associated with physical activity are relevant to the current concerns of moderately and highly active individuals. Therefore, our study supports recent evidence suggesting that automatic reactions toward exercise-related stimuli, including attentional capture, are involved in the regulation of physical activity. In recent years, researchers have developed new types of interventions to directly target these automatic processes (Cheval, Sarrazin, Pelletier, et al., 2016; Friese, Hofmann, & Wiers, 2011; Markland, Hall, Duncan, & Simatovic, 2015; Marteau, Hollands, & Fletcher, 2012). However, no study has yet assessed whether interventions designed to modify attentional bias, such as attention bias modification treatment (MacLeod et al., 2002), are effective in changing subsequent physical activity behaviors. Interventions aiming to promote the engagement in physical activity might benefit from testing the effectiveness of such attentional bias modification treatments (Boisgontier & Iversen, 2020). Moreover, in addition to having clear public health implications, such research will allow for the assessment of the potential causal role of attentional bias in physical activity regulation, thereby enriching the current theoretical perspectives.

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CONFLICT OF INTERESTS

The authors declare no conflict of interests.

AUTHOR CONTRIBUTIONS

All authors discussed and approved the design of the task. B.C. designed the analyses. B.C. analyzed the data. D.O. and M.P.B. prepared the figures. B.C., M.M., and M.P.B. drafted the manuscript. All authors critically appraised and approved the final version of the manuscript.

ETHICAL APPROVAL

This study was approved by the Ethics Committee of Geneva Canton, Switzerland (CCER2019-00065).

DATA AVAILABILITY STATEMENT

The data set is available the Zenodo open-access repository (https://doi.org/10.5281/zenodo.3371190).

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