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RESEARCH ARTICLE

Arousal and Vigilance: The Effects of Physical Exercise and Positive Mood on Attention

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Abstract

The present study was an effort to examine the extent to which the different states of arousal, as induced through exercise and manipulation of positive mood, interact to affect attentional processes. Thirty-four healthy participants were randomly assigned into 2 mood conditions: neutral and positive. A computerized auditory continuous performance test was used to measure attentional performance. Following baseline performance at rest and mood induction, participants completed the test while walking on a treadmill. Results showed that the impact of physical exercise-induced arousal on attention varied as a function of mood, such that while exercising, participants were able to maintain detectability scores and refrain from making an exaggerated number of commission errors only following positive (but not neutral) mood induction. These findings suggest that the impact of exercise on attention may depend on other key variables, such as mood.

Introduction

In recent years, attention and arousal level (or vigilance) has become matters of concern in the cognitive science domain, in which a growing body of studies using psychological and/or physiological approaches have been performed. Over the past decades, there has been a growing interest in the area of attention and arousal. Cognitive scientists have attempted to investigate potential influences of arousal states on attention, employing various psychological and physiological approaches [1,2]. Arousal is a general state of the central nervous system reflected in neural activity, which refers to the organism's disposition to react with varying degrees of energy or force [3]. The notion that cognitive performance is associated with arousal levels has long been part of the academic research, and a correlational relationship between performance of attentional tasks and levels of arousal has been reported [4,5].

According to Ashby, Valentin, and Turken, [6] there are at least two possible ways for experimentally influencing the state of arousal in cognitive studies: mood induction and physical exercise. Although arousal may increase with either positive or negative mood, it is the positive emotion that is considered to directly impact high-level cognitive processes [7,8]. Among the cognitive processes reported to have been influenced by emotional states include intuitive judgments, decision-making, attention, memory, and creative problem-solving tasks [9,10], suggesting that emotional influences on cognition may be deeply rooted in evolutionary continuity [11].

In an effort to explain the influence of positive mood on cognition, the broaden-and-build theory by Fredrickson and Branigan [8] proposes that different discrete positive emotions, such as amusement and contentment, produce broadening of attention, cognition, and action. They suggest that by inducing positive emotion, thinking becomes more integrative, inclusive, flexible, creative, and efficient. Ashby, Turken, and Isen [12] support this theory by pointing out many well-documented effects of improved cognitive processes due to positive feelings, attributing these effects to the increased dopamine release associated with positive feelings.

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Research on the relationship between physical activity and mental functioning has been a major interest for the past several decades. The psychological benefits attributed to physical activity, are well-documented and include, among others, emotional stability, academic improvement, and cognitive enhancement, such as memory, perception, and executive skills [13]. In their seminal study in older adults, Kramer, et al. [14] demonstrated a connection between aerobic fitness and cognitive enhancement. These authors compared a group of healthy older adults trained in aerobic exercises with controls and found improvements in several domains of executive functions, such as inhibition, planning, and working memory. In a meta-analytic study, Colcombe and Kramer [15] examined the hypotheses that aerobic fitness training had a positive influence on the cognition of sedentary adults. They found that fitness training increased cognitive performance 0.5 SD on average, regardless of the type of cognitive task, the training method, or participants' characteristics. More recently, physical exercises, and particularly aerobic exercises, have shown to enhance neurogenesis, the proliferation and development of neurons, in brain regions critical for learning and memory [16].

Another set of studies examined the immediate effects of physical exercise on cognition, with a specific focus on speeded measures of attention and vigilance. Unlike the generally positive findings of long-term benefits of physical exercises on cognitive functions, studies investigating the immediate effects of exercise on cognition, and/or examining cognitive performance while participants engage in physical activity, reported mixed results. For example, Davranche and Audiffren [17] found that reaction times in a choice task were 20 ms faster when tested during exercise, compared to when tested at rest. Notably, they found that the increase in reaction times did not change the response accuracy and concluded that submaximal physical exercise could improve the performances on a choice reaction time task. Tomporowski [18] reviewed a large body of literature on the immediate effects of exercise on cognition and reported that reaction times on various speeded tasks (e.g., simple detection, visual search, discriminative choice-response, and complex problem-solving tasks) were unambiguously faster during exercise than during non-exercise control conditions.

Contrary to these aforementioned studies, an early review of the exercise literature by Tomporowski and Ellis [19] failed to find empirical support for the notion that exercise had a significant positive influence on cognition. Wrisberg and Herbert [20] reported that fatigue produced by a treadmill run resulted in a brief transitory degradation of performance. Similarly, Isaacs and Pohlman [21] observed that participants' performance on timing task dropped during intense exercise. Travlos and Marisi [22] assessed young men in a choice-reaction-time test and a test of concentration during and following exercise. They reported that the exercise protocol had no effect on either measure [22].

Of course, some of the discrepancy among the aforementioned findings may be the result of methodological variability (e.g., exercised intensity, individual differences in aerobic fitness, and the type of cognitive assessments used in the study). However, the inconsistent findings across studies may also partly result from the failure by investigators to examine potential key variables that have been reported to affect cognitive performance. As discussed above, one such potential variable is mood, which has been repeatedly shown to influence various measures of cognition.

The present study was an effort to better elucidate the effect of arousal on attentional processes. As suggested by the aforementioned studies, there is a generally beneficial effect of positive mood on cognition. In parallel, the evidence for improved attention and information processing speed through exercise is mixed. Thus, although studies have examined the effect of mood and exercise on attention separately, to the extent of our knowledge, no study to date has examined the interplay among these parameters. Therefore, our primary objective was to examine the extent to which arousal, as induced through short bout of submaximal exercise and positive mood, interact to affect attentional processes, both in terms of accuracy and speed.

Method

Participants

Participants were 34 healthy students from a major Israeli university (76.4% women) between the ages 18-37 (Mean age = 22.85, SD = 3.125). Each participant received course credit for his or her participation. All participants gave written informed consent after receiving a full explanation of the research according to procedures approved by the Institutional Review Board.

Measures and procedure

Using randomized assignment, half the participants were assigned to positive mood induction, and the other half were assigned to neutral mood induction. Following baseline assessments, mood was manipulated using a well-standardized procedure through images from the International Affective Picture System [23]. The emotionalstimulus values of the slides were determined by prioraffective ratings obtained from a large sample of college students, and the slides were rated on valence (pleasure-displeasure) and arousal [24]. Positively valent pictures included opposite-sex nudes, romantic couples, babies, cuddly animals, sports scenes, and appetizing food, whereas neutral slides were generally of common household objects, such as a hair dryer, a book, and shoes [3].

Participants were instructed to focus on each image as it appeared on the computer screen and to allow them to be "carried" into a deeper affective state. Subsequently, participants were instructed to think of a situation in which they felt apathetic or happy and to write down the situation and the emotions they experienced. As a manipulation check, participants were asked to complete the Positive and Negative Affect Schedule [25]. The PANAS is a self-report checklist that contains two 10-item subscales designed for the assessment of positive affect (PA: active, alert, attentive, determined, enthusiastic, excited, inspired, interested, proud, and strong) and negative affect (NA: afraid, ashamed, distressed, guilty, hostile, irritable, jittery, nervous, scared, and upset). For each of the 20 emotion-related words, participants used a 5-point Likert scale (1 = very slightly or not at all to 5 = extremely) to rate the extent to which they experienced the given emotion.

All participants completed the Conners Continuous Auditory Test of Attention (CATA). This measure was administered twice, at baseline in a sitting position (before the mood manipulation), and while walking on the treadmill at a speed of 5 km/h (immediately following the mood manipulation). The CATA is a standard continuous performance test, with negligible practice effects [26]. It is administered in the auditory modality through earphones, thereby minimizing distractibility that may be difficult to overcome when exercising using visual tasks. The CATA task assesses auditory processing and attention-related problems in individuals aged 8 years and older. There are 200 scored trials, divided into 4 blocks of 50 trials. Within each block, 80% of the trials are warned trials, on which a low tone (warning) is followed by a high tone (target). The remaining 20% of the trials are unwarned, in which the high tone is played without warning. Participants are asked to respond as fast as they can to high tones on warned trials, but ignore those on unwarned trials.

The following key measures of attention were used in the analyses: Detectability (DPR) is a measure of the respondent's ability to discriminate non-targets (i.e., the high-tone sound on unwarned trials) from targets (i.e., the high-tone sound on warned trials). This variable is also a signal detection statistic that measures the difference between the signal (targets) and noise (non-targets) distributions. In general, the greaterthe difference between the signal and noise distributions, the better the ability to distinguish non-targets and targets. On the Conners CATA, this variable is reverse-scored so that higher raw and T score value indicate worse performance (i.e., poorer discrimination). Hit Reaction Time (HRT) is the mean response speed, measured in milliseconds, for all non-perseverative target responses made during the entire administration. Omissions (OMI) are missed targets. This error rate is displayed in % and indicates the percentage that the respondent was not responding to the target stimuli. Commissions (COM) are incorrect responses to non-targets, also displayed as error rate in % and indicate the percentage that the respondent responded to non-targets. As mentioned above, omissions and commissions indicate errors of participants, such that higher raw and T score values indicate worse performance (i.e., more mistakes). C is a signal detection statistic that measures an individual's natural response style in tasks involving a speed-versus-accuracy trade-off. Based on his or her score on this variable, a respondent can be classified as having one of the following three response styles: a *conservative* style that emphasizes accuracy over speed; a *liberal* style that emphasizes speed over accuracy; or a *balanced* style that is biased neither to speed nor accuracy. Higher T scores represent more conservative response style.

Statistical analysis

Potential age and gender differences between positive and neutral mood groups were examined using independent samples *t*-test and Chi-square test, respectively. Independent samples t-test was also performed to examine the effectiveness of the mood manipulation. A 2 × 2 Analysis of Variance (ANOVA) with repeated measures was conducted for each of the key dependent variables generated by the CATA software. Mood (neutral/positive) was the between subject variable and activity (rest/exercise) was the within-subject variable All dependent variables were converted to T-scores for the analysis, and there were no missing data.

Results

Independent samples *t*-tests demonstrated no significant age difference between the groups in the neutral (M = 22.6) and positive (M = 23.1) mood conditions, t (32) = -0.49, p = 0.63. Additionally, the distribution of males and females was identical in each group (4 males, 13 females). The procedure was well tolerated by all participants, with no dropouts. An independent *t*-test analysis of participants' positive score was conducted to examine the effectiveness of the mood manipulation, revealing a significant difference between the positive mood condition (M = 3.06) and the neutral mood condition (M = 2.24), t (32) = -3.196, p = 0.003.

A 2 × 2 ANOVA with repeated measures was conducted for each of the key dependent variables of the CATA. The descriptive and inferential statistics are presented in Table 1. As can be seen in Table 1, these analyses revealed a main effect of mood for DPR (η^2_p = 0.141). Participants discriminated non-targets from targets better in the positive mood condition (M = 46.9) than in the neutral mood condition (M = 51.2). A main effect of exercise was also revealed for DPR (η^2_p = 0.155), HRT (η^2_p = 0.130), and COM (η^2_p = 0.198). In contrast to hypotheses, participants discriminated non-targets from targets better when performing in the resting condition (M = 47.9) than in the exercise condition (M = 50.1). Participants also responded more slowly in the exercise condition (M = 33.9) compared to the resting condition (M = 32.8), and made more mistakes of commission type in the exercise condition (M = 49.7) in comparison to the resting condition (M

Table 1: Performance data on measures of attention.

	Neutral mood (n = 17)		Positive mood (n = 17)		Main effect of mood	Main effect of exercise	Interaction effect
	Baseline *M* (*SD*)	Sport *M* (*SD*)	Baseline *M* (*SD*)	Sport *M* (*SD*)			
DPR	48.65 (5.46)	53.65 (7.69)	47.12 (6.55)	46.59 (4.08)	**5.24**	**5.86**	**8.96**
HRT	32.53 (5.19)	34.12 (6.88)	33.06 (5.31)	33.71 (4.83)	0.001	**4.79**	0.848
OMI	45.53 (3.99)	46.41 (1.58)	45.59 (1.12)	45.53 (0.71)	2.47	2.12	2.78
COM	47.82 (7.03)	51.18 (5.94)	48.41 (3.34)	48.29 (3.46)	0.710	**7.92**	**9.82**
C	47.18 (8.05)	47.47 (7.53)	44.94 (5.18)	44.82 (4.85)	1.39	0.010	0.055

Note: DPR = detectability, HRT = hit reaction time, OMI = omissions, COM = commissions, C = response style. *F* values in bold indicate significance at $p < 0.05$ level.

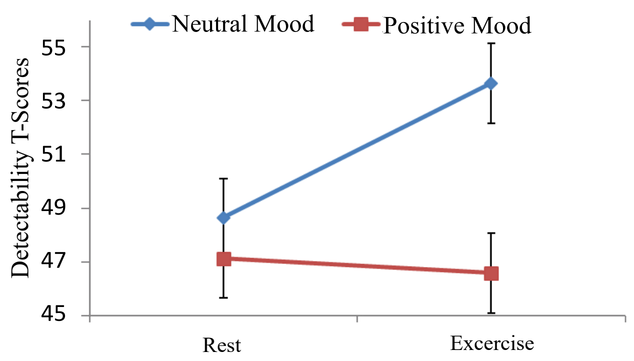

Figure 1: CATA detectability performance (higher T-scores reflect poorer performance).

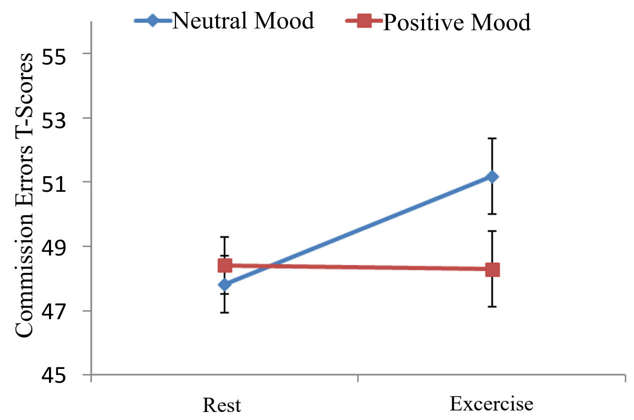

Figure 2: CATA % commission errors performance (higher T-scores reflect poorer performance).

= 48.1).

Most notably, the analyses revealed significant exercise × mood interactions. A significant interaction for DPR (η^2_p = 0.219), indicated that detectability was reduced in the exercise condition under neutral mood, but not under positive mood (Figure 1).

Similarly, there was a significant exercise × mood interaction for COM (η^2_p = 0.222), such that more commissions errors were made in the exercise condition under neutral mood, but not under positive mood (Figure 2). No other effects were statistically significant.

Discussion

This study examined the extent to which arousal, as induced through the interaction of short bouts of sub-maximal exercise and positive mood, affects attentional processes. Consistent with earlier studies, participants' ability to discriminate non-targets from targets was higher in the positive mood than in the neutral mood condition, albeit the effect size was small. In contrast to predictions, we found that exercise reduced performance on the attention task, both in terms of accuracy and speed, with small effect sizes. Most notably, however, were the findings regarding the combined effect of exercise and mood. We found that, while exercising, participants were able to maintain detectability scores and refrain for making an exaggerated number of commission errors only following positive (but not neutral) mood induction.

Nearly 30 years ago, Tomporowski and Ellis [19] classified the results from studies on physical exercises and cognition into four categories: studies finding a beneficial relationship, those finding a detrimental relationship, those finding both, and those finding no relationship. The authors indicated that conflicting results might represent a methodological artifact caused by the diversity of cognitive tasks used and the various physiological requirements of the exercise bouts in those experiments. Our study fell into the second category, such that when examining the main effect of exercise, there was a detrimental effect on both attentional accuracy and speed of response.

No doubt, Tomporowski and Ellis' [19] review underscores the importance of controlling a host of parameters that could influence cognitive performance. For example, according to Easterbrook's early cue utilization theory [27], a moderate intensity exercise could improve cognitive performance, whereas high intensity exercise would lead to a decrease in cognitive performance. This theory proposes that cognitive performance would be optimal under moderate intensity physical exertion, based on optimal arousal of the central nervous system. The theory claims that as arousal rises, attention narrows until it reaches an optimal level when only relevant cues are processed. Accordingly, any further increase in arousal would lead to further narrowing of attention and at some point even relevant cues may be missed. In line with this view, future studies could benefit from manipulating and monitoring arousal levels, such that optimal levels of arousal are identified and their effect on attention is assessed.

The cognitive cost of engaging in parallel tasks is also relevant in this context. Brisswalter, Durand, Delignieres, and Legros [28] discuss optimal and non-optimal demands of dual tasks when measuring attention during physical exercise. Although walking is considered an automatic physical activity, it is possible that walking on a treadmill, employed in the present study, proved to be new and unfamiliar operation, therefore requiring increased attentional resources for engaging in this activity. Thus, in accordance with this view, the shifting from execution of a single task (first administration of CATA in rest condition) to dual task (physical exercise and CATA) required non-optimal demands from participants, resulting in reduced attention.

It has also been argued that the type of cognitive task determines the effect of exercise on performance. Specifically, for complex tasks, such as decision making, physical exercise may lead to improvement, whereas simple perceptual tasks would deteriorate [29]. Additionally, Revelle and Loftuss' [30] proposed that higher activity levels immediately before the cognitive task (or in the present study during task performance), might inhibit short-term abilities to think quickly and efficiently, yet facilitating cognitive quickness after delays of 30 minutes or more. These views, therefore, suggest an inclusion of additional critical parameters for further investigation, such as task complexity and temporal proximity between physical exercise and cognitive measurement.

The beneficial effect of positive mood on attention, as well as the interaction between mood and physical exercise, found in the present study fits well within Fredrickson and Branigan's [8] broaden-and-build theory. In accordance with this theory, the arousal generated through positive mood might have resulted in a broadening of "attentional beam", thereby leading to improved attentional performance. Ashby, Turken, and Isen [12] conclude that "in both laboratory and field studies using a diverse set of measures and assessing a wide variety of contexts, positive feelings have been shown to lead to cognitive elaboration and flexibility, giving rise to more thoughts, more non typical thoughts, and innovative solutions to problems. In positive affect, thinking is flexible so that both usual and unusual aspects and senses of concepts may be accessible" (p. 531). Thus, it is possible that the positive mood induced in this study served both as a cognitive enhancer and a buffer against potentially detrimental effects of physical exertion.

In sum, despite the abundance of studies on the effects of exercise on cognitive performances, issues of optimal exercise intensity, temporal proximity between activity and cognitive assessment, and the differential effects on different cognitive domains remain largely unresolved. The current study adds to the growing body of literature, suggesting a beneficial effect of positive emotional arousal on attention and its potential contribution to maintaining continuous attention in the face of physical exertion. Thus, the present study found that the impact of physical exercise-induced arousal on attention varies as a function of mood. Future studies on this topic could further elucidate thisissue by manipulating or individually adjusting exercise intensity levels. Methodological advances in measuring brain function may provide researchers with more sophisticated methods of linking physiological arousal to specific cognitive processes, thereby providing additional information on the differential effect of arousal on cognitive functions.

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