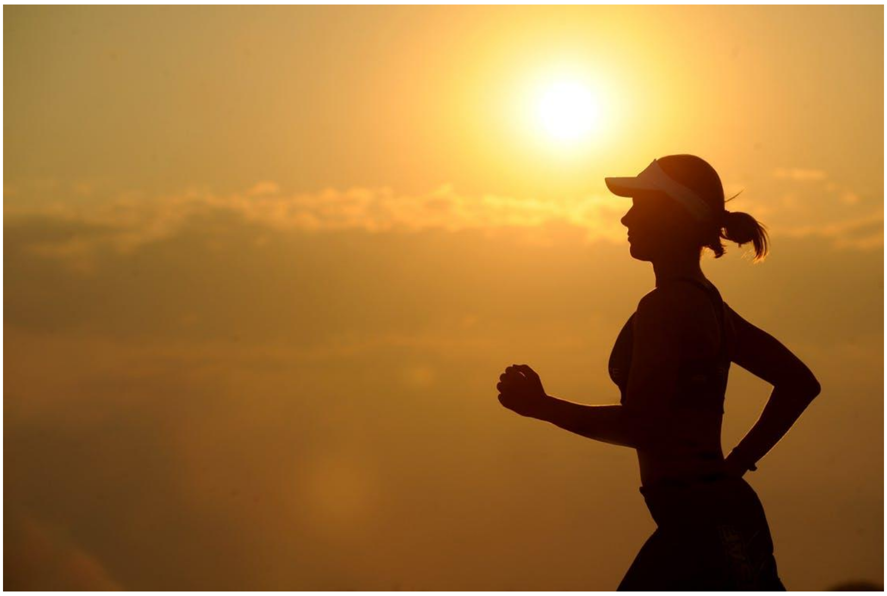
UNIVERSITY OF GOTHENBURG

DEPARTMENT OF
APPLIED IT

A REVIEW OF PHYSICAL ACTIVITY'S EFFECT ON MOOD

Through the Lens of the HPA Axis



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Abstract

Engagement in physical activity (PA) has been said to trigger a chain reaction of events which can alter our mood state. One recently implicated component is the hypothalamic-pituitary-adrenal (HPA) axis, involved in the reaction to physical and psychological stressors. This study aims to investigate mood through the lens of the HPA axis when performing PA, specifically aiming to reconfirm this as a paradoxical relationship and if *the cross-stressor adaptation hypothesis* can then serve as a possible explanation. This study also aims to identify additionally contributing factors to the relationship through examinations of methodological approaches. Furthermore, cognition's potentially influencing role is specifically examined. A systematic literature review was conducted where data of study design, method, population and results was extracted from each of the studies. Out of the 47 identified studies, a variety of responses in mood and HPA axis activity was found following PA, and the methods employed also varied. Most of the identified studies exclusively studied males and participants under the age of 30. Cognitive aspects were found to produce significant differences or to be significantly affected when studies alongside PA, mood and the HPA axis. The varied results and methods did however not allow for a comprehensive analysis and the overrepresentation of younger males did not allow the results to be generalised to the entire population. Further analyses such meta-analyses on a smaller scale is needed.

Keywords

Mood, Physical activity, HPA axis, The cross-stressor adaptation hypothesis, CRH, Exercise, Cortisol, Cognition

Titel

En översikt kring fysisk aktivitets påverkan på humör: genom HPA-axeln

Sammanfattning

Deltagande i fysisk aktivitet har sagts utlösa en kedjereaktion av händelser som kan förändra vårt humör. En nyligen förslagen påverkande komonent är HPA-axeln, som är involverad i responsen till fysiska och psykologiska stressorer. Denna studie ämnar att genom en systematisk litteraturöversikt, undersöka humör, genom HPA-axeln, under utförande av fysiskt aktiva aktiviteter. Specifikt fokus riktas mot att återbekräfta relationen mellan humör, HPA-axeln och fysisk aktivitet som ett paradoxalt förhållande samt att undersöka ifall *'the cross-stressor adaptation hyothesis'* kan ses som en valid förklaring. Vidare ämnar denna studie till att identifiera andra möjliga bidragande faktorer och förklaringar till den identifierade relationen där möjliga påverkningar från tidigare forsknings metodologiska tillvägagångssätt samt kognitionsrelaterade processer undersöks specifikt. Data från studiers design, metod, studerade population och deras resultat extraherades från var och en av de 47 identifierat relevanta studierna. En mängd olika resultat hittades i fysisk aktivitets påverkan på humör och HPA-axeln samt en stor variation i studiernas metod. En majoritet av studierna studerade uteslutande män och deltagare under 30 år. Kognitiva aspekter visade sig ge signifikanta effekter på eller påverkades signifikant av fysisk aktivitet, humör och HPA-axeln. De varierande resultaten och metoderna möjliggjorde dock inte en heltäckande analys och överrepresentationen av yngre män gjorde det inte möjligt att generalisera resultaten till hela befolkningen. Vidare analyser, exempelvis meta-analyser på en mindre skala behövs.

Nyckelord

Humör, Fysisk aktivitet, HPA-axeln, Cross-stressor adaptation hypothesis, CRH, Träning, Kortisol, Kognition

Foreword

This is a collaboration between the authors Susanna Karlkvist and Anton Wickberg. The foundational aspects of this review were equally divided between the authors where both outlined the methods of analysis, performed the database searches and extracted data to an equal amount. Wickberg majoritively analysed the identified studies's methodological approaches and the presence of cognitive aspects considered throughout the studies. Karlkvist majoritavly reported the results of the studies and their correlational analyses and structurised the report. The introduction, method and discussion are mainly written by Karlkvist with regular contributions from Wickberg.

Both authors extend their greatest thanks to William Thompson for excellent guidance and additional input. Karkvist wants to thank AntonWickberg for his uplifting spirits, perseverance and ability to structurize even the most overwhelming amounts of data. Wickberg wants to thank Susanna Karlkvist for being a terrific co-author of this review. Your natural scientific eye for detail and coherence in combination with your strong value of never compromising on quality forced me into new ways of thinking. Thank you for a truly joyful learning journey.

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1 Introduction

Mood as a subject of research has been of interest in several different fields, for instance, within psychology (Shields et al. 2017), neuroscience (Martínez-Díaz & Carrasco, 2021), cognition (Chepenik et. al. 2007) and athletic performance (Vaughan & McConville, 2021). Emotions, defined as psychoneural processes that can; cause affective experiences of valence and arousal; generate cognitive processes; and motivate goal-directed and adaptive behaviour (Tyng et. al. 2017), are strongly intertwined with mood. Mood besets these same processes but is often thought to last longer (Tyng et. al. 2017) and be less intense (Larsen, 2009). A common division of mood relates to an organisation into either positive or negative affect. Affect can be defined as a broader term encompassing all types of emotive states (Niven, 2013). Negative affect can then entail a mood state of negative valence such as anger and positive affect can entail a mood state of positive valence such as joy (Watson et al., 1988).

Previous mood research has been aimed towards a multitude of purposes including: 1) developing effective treatments which can alleviate symptoms of mood disorders (Klibert et al. 2022), 2) determining the effects of physical activity (PA) on mood (Basso & Suzuki, 2017) and 3) examining its effects on different cognitive processes (Fredrickson, 2004; Mohanty & Suar, 2014; Parrott & Sabini 1990; Shukla et al. 2018).

Progress has been made in several of these research fields, yet the question of exactly which role mood plays in each field of study remains. Specifically, the answers to questions regarding how mood can be affected, by what mood can be affected and to what extent, remains unanswered. An answer to these questions has recently been suggested in the study of the relationship between PA and mood. Indications suggest that the hypothalamic-pituitary-adrenal (HPA), which is activated by PA (Chen et al., 2017), may be able to influence mood (Martínez-Díaz & Carrasco, 2021).

2 Previous research

2.1 Physical activity, mood and the HPA axis

2.1.1 Physical activity and mood

PA details any muscle-caused bodily movement requiring energy expenditure. Exercise, a subcategory of PA includes planned, structured, repetitive movement with the purpose of improving or maintaining physical capacity (Dasso, 2019). There is a well documented positive effect of exercise on mood and well-being (Kanning & Schlidt, 2010). Well-being is closely related to mood but refers to a combinatory state of feeling and functioning well (Ruggeri et al., 2020).

Furthermore, research suggests that participation in regular day-to-day physically active activities correlates with an increased presence of positive mood states (Kanning & Schlidt, 2010) and that individuals regularly engaging in PA are less likely to suffer from anxiety (Ströhle et. al. 2007) and other mood disorders (Leone et al. 2018).

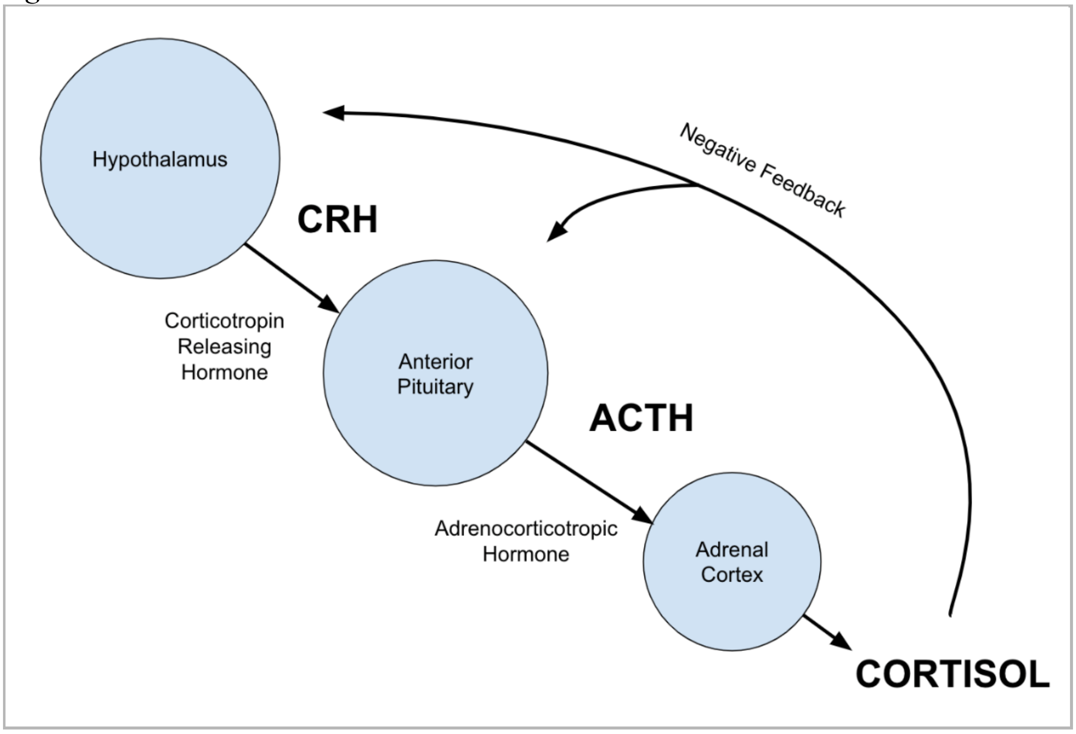
Contrarily, research has also found that exercising can have negative effects on mood, and it has been linked to decreases in mental health when performed excessively (Chekroud et al. 2018).

2.1.2 Relations to the HPA axis

In trying to understand the relationship between mood and PA, the HPA axis has come of interest (Mikkelsen et al. 2017). In detail, the HPA axis stands for the relationship between the hypothalamus, the anterior pituitary gland and the adrenal cortex. Its main responsibility is the adaptation to physical stressors, i.e., PA and exercise, and psychological stressors (Lopez et al., 2021). As a response to stress, (see Figure 1) the hypothalamus dispatches corticotropin-releasing hormone (CRH) to the pituitary gland which triggers the release of adrenocorticotropic hormone (ACTH) into bodily circulation, before it reaches the adrenal glands (Smith & Vale, 2006). Both the hypothalamus and the pituitary gland are part of the brain's limbic system and are therefore closely located, however the adrenal glands are located at the top of the kidneys. When reached by ACTH, the adrenal glands are stimulated to produce and secrete glucocorticoids (Smith & Vale, 2006). In human anatomy, the main responsible glucocorticoid is cortisol, which has been found to relate to differentiated mood states (Chen et al, 2017). The released cortisol also inhibits further activation of the hypothalamus and anterior pituary though a negative feedback loop (see Figure 1).

There is further evidence suggesting a dose-respondent relationship between PA and the HPA axis (Caplin et al., 2021), and the intensity of a stressor has been termed a major factor determining the response of the HPA axis (Herman et al., 2016). This suggests that the intensity and amount of PA could alter the response of the HPA axis. The HPA axis is further ruled by a circadian rhythm (Cohen et al., 2014), resulting in higher cortisol levels upon waking which increase further for about 30 minutes and reaches its peak, before steadily decreasing throughout the rest of the day (Hellhammer et al., 2009).

Figure 1. The HPA axis



2.1.3 Paradoxical relations

The relationship between PA, mood and the HPA axis has been described as a paradox (Chen et al., 2017). This is because PA as a stressor will activate the HPA axis leading to increased levels of circulating cortisol in very much the same way psychological stress triggers the HPA axis. Further, as negative affect has been associated with higher cortisol levels (Smyth et al., 1998) and longer periods of chronic stress is very much associated to both higher cortisol levels and a detrimented mood (Chen et al., 2017), paired with the afore-mentioned positive effect exercise has on mood, a contradictory relationship is established. Moreover, regularly active individuals seem to have an attenuated physiological response during exposure to stressful stimuli (Ensari et. al., 2020) meaning exercising may even have stress-buffering effects.

Attempts to explain this effect have resulted in the postulation of t*he cross-stressor adaptation hypothesis.* The hypothesis states that as regularly exercising people adapt to the physical stressor of exercise, i.e., improving their fitness level, they will also become more adept at handling psychological stressors due to their physiological changes (Arvidson et al., 2020). PA is thought to be able to regulate the HPA axis, causing a higher activation threshold and a reduction of cortisol reactivity to stress stimuli (Pauly et al., 2019). When exposed to a stressor, trained individuals should then experience less of a disturbed mood and at the same time show an attenuated physiological response when compared to less physically active individuals. This is thought to be caused by an influencing role of the HPA axis on mood. The results of existing research of the cross-stressor adaptation hypothesis have however proved inconclusive (Arvidson et. al. 2020).

2.2 Cognitive aspects

2.2.1 Connections between mood and cognition

Connections between mood and cognition have been studied for several years. As a divider, cognition can be separated into "hot" cognition and "cold" cognition. Hot cognition encommpasess cognition ladden with emotional processing (Douglas et al., 2020), therefore mood is seemingly able to influence cognitive processes. Research has indicated facial emotion recognition (Chepenik et. al., 2007), memory (Chepenik et. al. 2007), executive functioning (Oaksford et. al., 1996) and visual perception (Vegas & Laurent, 2021) as some of the cognitive processes alterable by mood state. Furthermore, cognitive deficits are heavily implicated in patients with mood disorders such as major depressive disorder and bipolar disorder. In further studies of depression, it has been found that negative biases in emotional processing are part of its pathophysiology and that changing the pattern of emotional processing serves as a successful treatment (Douglas et al. 2020), which in turn suggests that cognition also may be able to alter mood state.

2.2.2 Effects of the HPA axis and physical activity on cognition

The HPA axis further appears to have explicit effects on cognition (Chen et al. 2017). Elevated cortisol levels have been found to be associated with lower cognitive functioning, specifically regarding episodic memory, executive functions language, spatial memory and processing speed (Ouanes & Popp, 2019). At the same time, exercising, which should temporarily increase cortisol levels, has been strongly indicated as a promoter of cognitive health (Gomez-Pinilla & Hillman, 2013). Currently, it is uncertain exactly how PA can improve cognition, though it seems it can be aided both through increasing cardiovascular fitness and through direct motor activity (Netz, 2019). Additionally, the HPA axis has been proven to be particularly involved in the pathogenesis of mood disorders (Bao & Swaab, 2019; Hoge et al. 2019) and most recently research suggests that administration of drugs targeting HPA axis related hormones might beneficially impact the cognitive health of patients with mood disorders (Soria et. al., 2018).

It appears that there is a connection between cognition and the relationship between PA, mood and the HPA, where mood and cognition can simultaneously affect each other, the HPA axis and its related hormones can impact cognition and PA can possibly promote cognitive health.

3 Current study

The current study aims to examine the existing research of PA's effect on mood and HPA axis activity and see if there are any indications of the HPA axis being able to influence mood. Through a systematic literature review, existing research will be examined for re-confirmation of the paradoxical relationship between PA, mood and the HPA axis, along with an enquiry of results supporting the cross-stressor adaptation hypothesis as a possible explanation. Through the scope of this review, the reconfirmation is dependent on two parts; *part 1*) that following acute PA an increase of HPA axis activity co-occurs with a decremented mood state, and *part 2*) that after bein regularly physically active for a longer period of time, a lower degree of HPA axis activity is concurrent improved mood states. Additionally, since there are indications that the response of the HPA axis is dose-respondent, more intensive exercise should produce a more pronounced response of the HPA axis than less intensive exercise. In this review, support for the cross-stressor adaptation hypothesis will be determined by results of negative correlations between HPA axis activity and positive mood state. This should be seen as only a preliminary inqury as no causal relationship would be determined.

Furthermore, as previous research has reached mixed results, additional focus is extended to the design and implemented methods of the research, and which populations have been studied. The analyses of study methods are specifically aimed towards examining how mood and HPA axis activity is quantified and how the PA is implemented, the aim being to point towards possible discrepancies which could explain the differentiated results.

Due to the relationship between each of these variables and cognition, a supplementary analysis within the identified research will be conducted to see if and which cognitive factors are considered. The results of this will indicate if the relationship of cognition to PA, mood and the HPA axis is mirrored in the existing research or if further exploration is needed.

Through the review, the aim is therefore to answer these five research questions:

1. Does the existing research confirm a paradoxical relationship between PA, mood and the HPA-axis?
2. Does the existing research support a dose-respondent relationship between PA and HPA axis activity?
3. Does the existing research yield support for the cross-stressor adaptation hypothesis?
4. Could differences in methodological approaches help explain possible differentiated results?
5. Is the connection to cognition mirrored in the identified research and what do the results suggest?

4 Method

4.1 Design

Data was collected through a systematic literature review. Relevant search words were divided into three categories of interest; 1) mood related, 2) HPA-axis related, and 3) PA related. The three categories were then combined by AND phrases (see Figure 2).

Figure 2. Illustration of search words, of the three different categories

mood **OR** "mood state" **OR** "state of mind" **OR** feeling* **OR** "psychological states" **OR** "psychological state"
AND
"hypothalamic-pituitary-adrenal axis" **OR** HPA **OR** hypothalamus **OR** "anterior pituitary gland" **OR** "adrenal cortex" **OR** "CRH neurons" **OR** "hypothalamo-pituitary-adrenal" **OR** cortisol **OR** CORT **OR** ACTH **OR** glucocorticoid **OR** "adrenocorticotropic hormone" **OR** pituitary **OR** "corticotropin-releasing" **OR** corticosteroid*
AND
runn* **OR** exercis* **OR** "endurance training" **OR** "heart rate-boosting activity" **OR** training **OR** "physical activity" **OR** HIIT

- Search words related to mood, - Search words related to the HPA axis, - Search words related to PA

Search words related to mood were chosen to identify research with examinations of current mood states. Associated words such as 'emotions' and 'well-being' were excluded due to the former being associated with less stable states and the latter to general health. 'Affect' was not included due to its use as a collective term of all emotive states. 'Feeling*' was included in an attempt to catch phrases such as "feelings of fatigue" or "negative feelings". Search words related to the HPA axis were chosen to identify research with examinations of the hormones and brain structures most closely related to the stress response elicited by the HPA axis. Search words related to PA were chosen to encapsulate a broad variety of ways to be physically active.

Further searches were performed through the identified research to see whether cognition was considered or studied throughout the research. Relevant factors of cognition were defined as; 1) perception, 2) attention, 3) memory, 4) representation, 5) planning, and 6) communication, as discussed by Goldstone (2019). Additional search words were then assembled (see Figure 3), each representative of cognition or one of the identified cognitive aspects.

Figure 3. Illustration of search words related to cognition

cogni* **OR** percep* **OR** percei* **OR** attention **OR** attent **OR** memor* **OR** remember* **OR** represent* **OR** plan* **OR** communicat*

- Search words related to cognition

4.1.1 Exclusion and inclusion criteria

For inclusion in the review, at least one search word from each of the three categories needed to be present. There also had to be an explicitly stated and reported measurement of mood and HPA axis activity. If additional conditions were studied alongside the effect of PA, e.g., the effect of meditation in comparison to running, there had to be separately reported results in order to eliminate the appended confounding factors. This allowed extraction of data only relating to the effects of PA.

Studies were excluded if they only adopted PAs involving meditation-like exercises such as yoga and qigong due to the acknowledged effects of diaphragmatic breathing on mood states and cortisol levels (Ma et. al. 2017). No exclusionary criteria were set regarding type of study.

Further exclusion criteria were participants affected by substance-abuse or doping as it may cause dysregulation of the HPA axis (Lovallo, 2006; Baumann, 2012), and participants affected by disease or other disorders except mood disorders and overtraining syndrome. Lastly, studies with another possible stressor present, e.g., active sports competition (Samelko et al. 2020) were excluded, unless there were equal stressors between the different conditions and PA level was used as an independent factor.

4. 2. Procedure

The systematic searches were conducted through the databases PubMed, WebofScience, PsycInfo and CINAHL. All articles were first screened based on title names and abstracts and included if they seemed to fulfil the inclusion criteria. After removing duplicates, shorter reviews were conducted to additionally ensure that the identified research fulfilled the inclusion criteria. After this stage articles were thoroughly analysed on account of relevant aspects of the analysis, categorised and examined for exclusionary criteria. The searches of the databases were dived between both authors equally and all screenings were done manually by the authors.

The studies were originally clustered into divisions of interventions, lifestyle-related, sport-related and mental health-related studies, based on a combined interpretation of study span, population, setting and purpose. This approach turned out to be too vaguely defined, thus risking big overlaps between for example the lifestyle and mental health category. Another effort that had to be abandoned was trying to categorise PA volume by using WHO ‘s framework *Global Recommendations on Physical Activity for Health* (WHO, 2010). In the framework WHO divides PA into three scales: low, moderate and vigorous by mapping the activity on a 1-10 scale compared to a state of rest (where rest is 0). But it was soon realised that the studies used a wide range of different ways of reporting PA where some studies used the exact WHO scale, others VO_2 max, while others solely reported type of activity. Thus, the WHO scale left too much freedom of interpretation to the authors of this review. On the final categorisation iteration, the studies were instead worked into six different categories based on how the PA was implemented and when mood and HPA axis activity was measured connecting to stressors. This division was based on some common patterns found through the previous iterations of categorisation. The six categories constituted: 1) *acute exercise effects*, 2) *effects of exercise conditions*, 3) *effects of training load*, 4) *physical activity level's effect on mood and the HPA axis*, 5) *long-term interventions*, and 6) *physical activity's stress-buffering effects*. The final categorisation was performed by one author and when there was a potential overlap between categories, the studies were assessed by both authors and categorised into where it seemed most fitting.

4.2.1 Acute exercise effects

These studies implemented exercise as a stressor and comparisons were made either between groups with an experimental and control group, or within groups between baseline and post-exercise scores. Data was collected of the type and duration of exercise. It was noted when a statistically significant result was present in measures relating to mood or HPA axis-related hormones, after exercise. Of particular interest was if exercising was concurrent with a statistically significant increase of the HPA axis activity or worsened mood states. This would provide insight into part 1 of the paradoxical relationship between PA, mood and the HPA axis, connecting to research question 1.

4.2.2 Effects of exercise condition

These studies implemented different conditions of exercising and made comparisons between the conditions. Their analyses were based either on comparisons between groups or within groups. Data was collected of how exercising differed across conditions. It was noted when a statistically significant result was present in measures relating to mood or HPA axis-related hormones after exercising. Of particular interest was if different exercise conditions could elicit significantly different responses in mood states and HPA axis-related hormones across conditions, connecting to research question 4.

4.2.3 Effects of training load

These studies implemented different training conditions and made comparisons between variations of training load determined by manipulation of training intensiveness or volume. Their analyses were based either on comparisons between groups or within groups. Data was collected of the type of training, how it varied regarding training load and the study span. It was noted when significant differences were recorded in any measures relating to mood or HPA axis-related hormones following variations of training load. Of particular interest was if there were significant differences between conditions of higher and lower training load where more training is concurrent with a higher HPA axis activity and worsened mood states. This could confirm a dose-respondent relationship between PA and the HPA axis and provide insight to its effect on mood, connecting to research question 2.

Due to the large number of studies qualifying for this category, they were divided into further subcategories; 1) *cycling*, 2) *swimming*, 3) *running*, 4) *rowing*, 5) *basketball* and, 6) *mixed*. Division into these categories was based on which type of training was tested. This allowed for a preliminary overview of which sport categories have been mostly studied regarding varying training load. Analysis of the category included all the subcategories into one.

4.2.3 Physical activity level's effect on mood and the HPA axis

These studies assessed participants's PA level and examined it against their mood state and HPA axis activity. Data was collected on how subjects' PA level was assessed. Of interest was if there were significant differences in measures relating to mood state and HPA axis-related hormones due to PA level. This would provide insight into part 2 of the paradoxical relationship between PA, mood and the HPA axis, connecting to research question 1.

4.2.4 Long-term interventions

These studies implemented PA through long-term interventions of exercise programs. Comparisons were made between groups with an experimental and control group, or between baseline and post-intervention scores within groups. Data was collected of the type of training program and duration of the intervention. It was noted when there was a significant difference in measures relating to mood or HPA axis-related hormones following the intervention. Of particular interest was if there were any significant differences observed where the effects of the intervention show improved mood states and lowered HPA axis activity. This would provide insight into part 2 of the paradoxical relationship between PA, mood and the HPA axis, connecting to research question 1.

4.2.5 Physical activity's stress-buffering effect

These studies assessed participants's PA level and made comparisons between and within groups when exposed to stressors. Data was collected on how the participants' PA level was assessed or the population descriptives given to define their level of PA, e.g., elite sportsmen. It was noted when there was a significant difference in measures relating to mood or the HPA axis-related hormones following the stressor. Of particular interest was if more physically active participants showed a significantly lower HPA axis activity response or a better mood compared to less physically active participants. This would provide insight into part 2 of the paradoxical relationship between PA, mood and the HPA axis connecting to research question 1.

4.2.6 Extracted data

4.2.6.1 Results

Significant results were determined as obtaining $p < .05$. In studies that did not report p-values as their threshold for statistical significance, significant results had been determined by the authors by calculations of standardised thresholds for small, moderate, and large differences of pooled between-subject standard deviations with the chance of the difference being substantial or trivial determined through the following scale: 25–75%, possibly; 75–95%, likely; 95–99.5%, very likely; and .99.5%, most likely (Hopkins et al., 2009). Results above 75-95% were included as statistically significant results in this review.

Valence of mood states was determined by the definitions included in the studies. Where no definition was given, states and scales connected to words such as happiness, vigour and relaxation were judged as positive, as positive affect has been characterised as pleasurable and energetic states (Watson et al., 1988). Negative mood states were judged by connections to words such as stress, fatigue, exertion and anxiousness, as negative affect has been characterised as unpleasurable and distressing states (Watson et al., 1988). An increase of positive affect was judged as an improved mood whereas an increase of negative affect was judged as a worsened mood. In studies where mood was assessed through the existence of mood disorder symptomatology, improved mood states were defined as a decrease in symptomatology and an increased symptomatology of mood disorders was judged as worsened mood.

Additionally, it was noted if correlational analyses between mood and HPA axis-related hormones were performed. All explicitly stated correlational analyses between the relevant variables were included in the results of the review. Consistently appearing significant correlations would support the cross-stressor adaptation hypothesis, connecting to research question 3.

4.2.6.2 Analyse of research methods

Data was collected on how mood was assessed and quantified. Data was also collected regarding methods of hormonal sampling. The data was clustered, and analyses were performed regarding which methods of mood quantification and hormonal sampling was used most often, connecting to research question 4.

4.2.6.3 Demographics

In each study, data was collected on which population is studied regarding sex and age. Data was collected of how many studies exclusively studied male or female subjects, or if both sexes were studied. Further calculations of total number of participants of each sex were conducted. For an overview of the age ranges of the studied populations, all studies were divided into a category based on their reported age range (<30, 30-60, 60<, <30-60, 30-60<, <30-60< or uncertain). The extraction of demographic data connects to research question 4.

4.2.6.4 Cognition

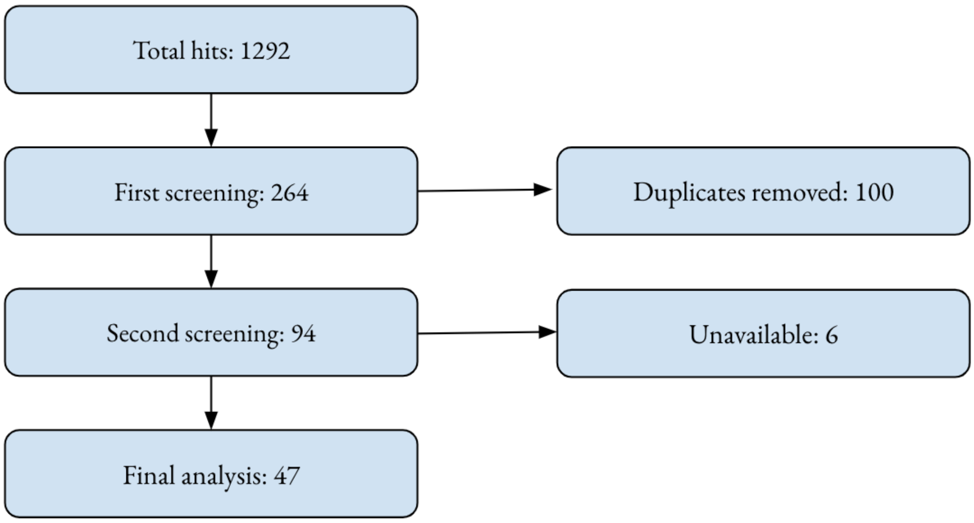
Searches within the texts of the identified studies were performed to examine if any cognitive dimensions were considered or studied. Determined as explicitly mentioning or discussing “cognition” or one of the 6 dimensions (perception, attention, memory, representation, planning and communicating) as a field of inspiration or possible influence, a calculation of cognitive consideration was conducted. Following, the studies were examined to see if cognition was explicitly studied alongside PA, mood and the HPA axis. The results of these studies were then further analysed, connecting to research question 5.

5 Results

5.1 Database search

47 studies were identified fitting the inclusion and exclusion criteria. Publishing year ranged from 1989-2021. Searches were conducted at the end of year 2021. Additional results of the database searches are presented in Figure 4.

Figure 4

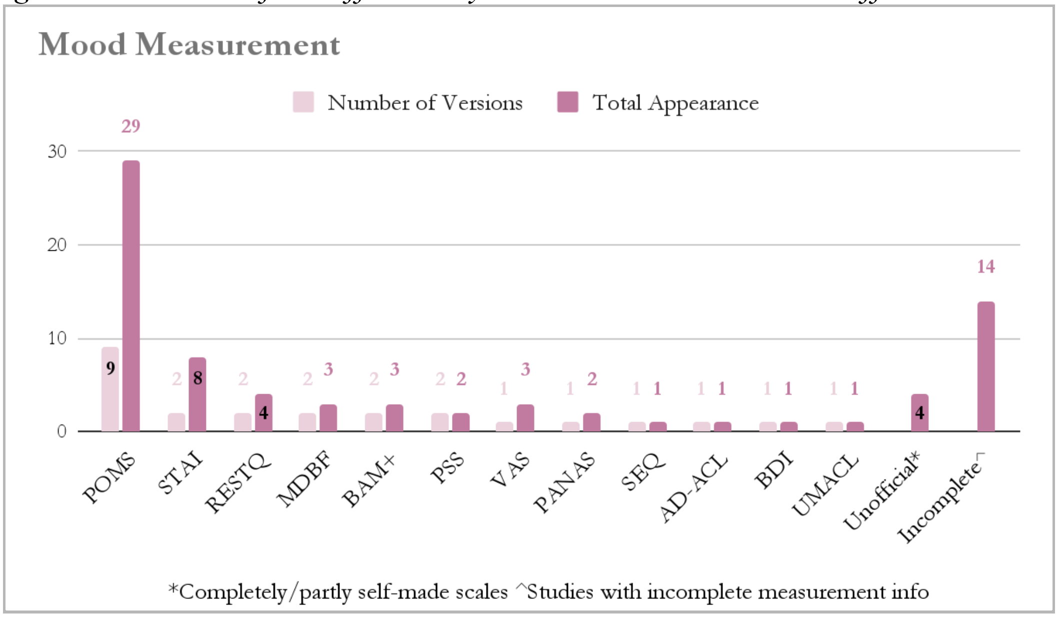


5.2 Research methods

5.2.1 Quantification of mood

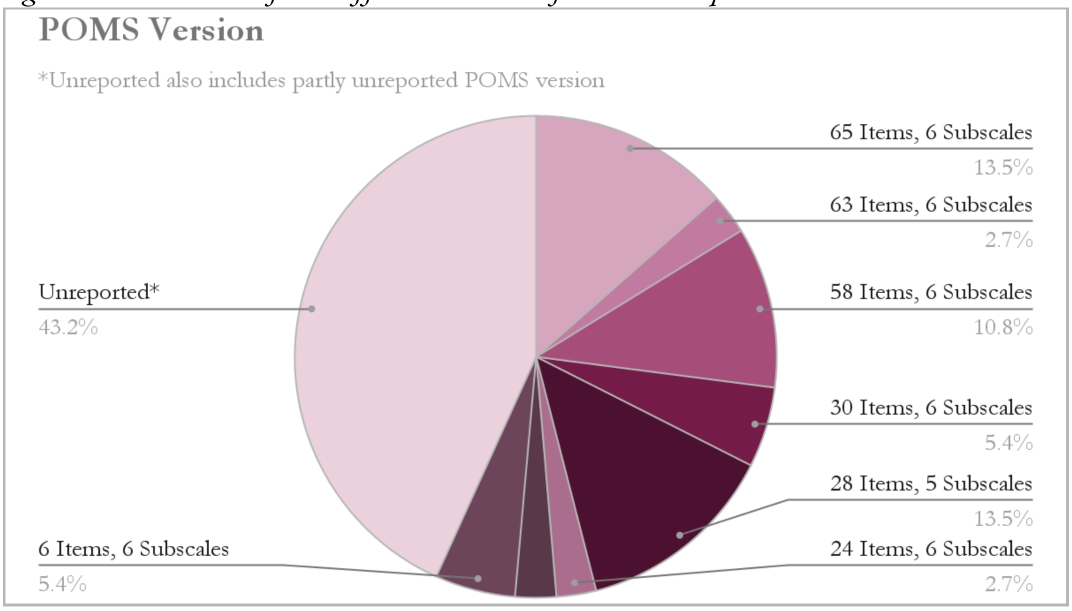
Mood was exclusively measured by self-report questionnaires, where results were calculated as a score on a scale, often including subscales covering different aspects of mood. 14 studies (30.43%) used more than one measure of mood. 12 different ways of measuring were identified where the Profile of Mood States questionnaire (POMS) was most often used. The second most common measurement was State-Trait Anxiety Inventory (STAI) followed by the Recovery-Stress Questionnaire for Athletes (RESTQ-S). Additional scales used were the Perceived Stress Scale (PSS), the Multidimensional Mood State Questionnaire (MDBF), the Positive and Negative Affect Schedule (PANAS), the Beck Depression Inventory (BDI), the Brief Assessment of Mood (BAM+), the Sport Emotion Questionnaire (SEQ), the UWIST Mood Adjective Checklist (UMACL), the Activation Deactivation Adjective Check List (AD-ACL) and the Visual Analog Scale (VAS). Some studies included unofficial measurements of mood which were divided into its own category (see Figure 5).

Figure 5. Illustration of the different ways mood was assessed and their different versions.



Further variations were found within the standardised measurements by their implementation of different versions. This was commonly found in the POMS measure, but different versions could also be identified in other measures. In the 29 (61.7%) studies that used the POMS questionnaire, eight versions were identified by their differentiated number of items included in the questionnaire, and by their different number and types of subscales reported (see Figure 6). 15 (32.6%) of the studies implementing the POMS questionnaire did not report the number of items and subscales included (see Figure 6). Finally, the formulas used to calculate total mood scores of the POMS questionnaire differed across the studies and with some studies opting out of reporting a total score.

Figure 6. Illustration of the different versions of the POMS questionnaire.



Following are depictions of all the positive (see Figure 7) and negative (see Figure 8) subscales used throughout all the studies. Figure 9 depicts the different formulas for calculations of mood scores of the POMS questionnaire.

Conclusively, all studies relied on methods of self report to assess mood states. A variety of self-report methods were implemented and even though the POMS questionnaire was in clear majority, the implementation of it differed across studies. Mood quantification was additionally varied with the multiple subscales, varying across the studies. Thus, no common formula standard could be found for quantification of mood states.

Figure 7. Positive mood subscales reported in the studies

Anxiety Absent (AA)	Excitement (Ex)	Hedonistic Tone (HT)
Calm-Nervous (C-N)*	Exhilaration (Exh)	Positive Affect (PA)
Energetic Arousal (EA)	Friendliness (Fr)	Positive Feelings (PF)
Elation (El)	Good-Bad Mood (G-BM)*	Positive mood (PM)
Energy (En)	Happiness (Ha)	Vigour (Vi)

* *Two-dimensional scale*

Figure 8. Negative mood subscales reported in the studies

Anger (An)	Exertion (Exe)	Physical Complaints (PC)
Annoyance (Ann)	Exertion-Relaxation (E-R)*	Social Stress (SS)
Anxiety Present (AP)	Fatigue (Fa)	Stress (St)
Anxiousness (Anx)	Fatigue/Stress (F/S)	Tense Arousal (TA)
Conflict/Pressure (C/P)	General Fatigue (GF)	Tension (Te)
Confusion (Co)	General Stress (GS)	Tiredness (Ti)
Dejection (De)	Lack of Energy	
Depression (Dep)	Negative Affect (NA)	
Emotional Stress (ES)	Negative Feelings (NF)	

* *Two-dimensional scale*

Figure 9. POMS mood summasions reported in the studies

Global Mood Score (GMS)	Total Score (POMS-t)
Global Mood (GM)	Total Score (TS)
Overall Mood Score (OMS)	Total Mood Disturbance (TMD)
POMS Score Index (iPOMS)	

5.2.2 Assessment of HPA axis activity

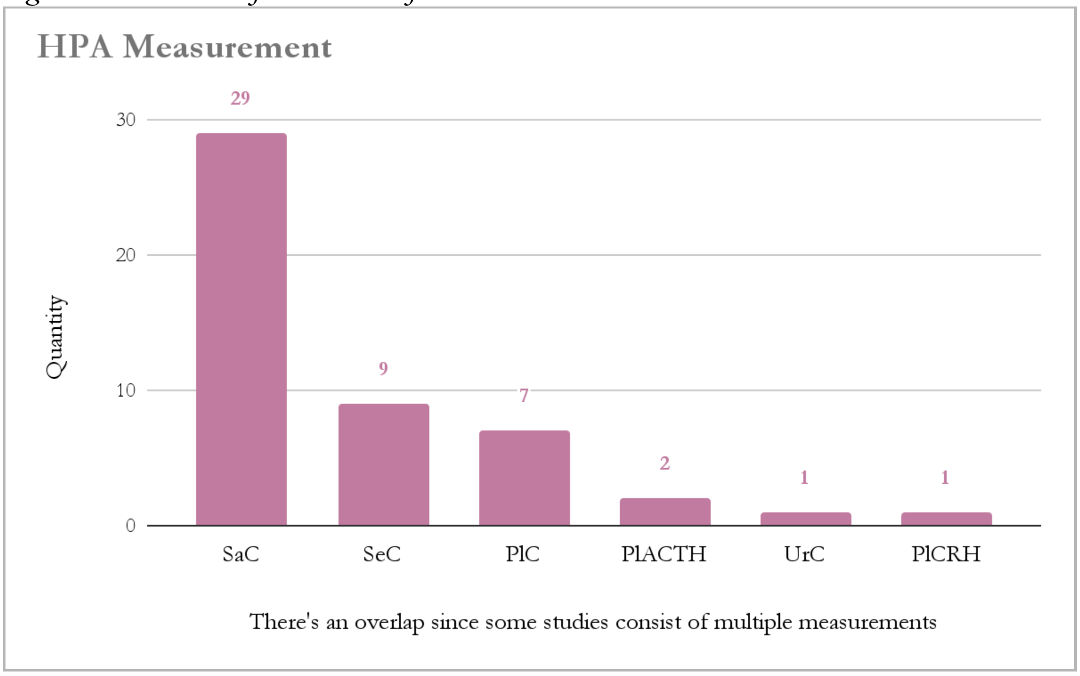
The activity of the HPA axis was measured by targeting three types of hormones: cortisol, adrenocorticotropin (ACTH) and corticotropin releasing hormone (CRH). A majority of 44 studies (93.6%), measured HPA axis activity only through a single hormone where the remaining three studies (6.4%) included measures of two hormones. A measure of cortisol was included in all the 47 studies, ACTH was included in two of the studies, and CRH was included in one of the studies.

Hormones levels were assessed by collection of saliva, plasma, serum or urinary samples. A majority of 46 studies assessed hormone levels only through one method. One study included two different methods of assessment, serum cortisol (SeC) and plasma cortisol (PlC).

Salivary cortisol (SaC) was the most used way of assessment, followed by SeC, PlC, plasma ACTH (PlACTH) and lastly plasma CRH (PlCRH) and urinary cortisol (UrC) (see Figure 10). Possible explanations of SaC's popularity are described in some of the studies. SaC sampling is described as a method of preference due to the stress reduction triggered by the noninvasive collection itself (Marques et al., 2010). The reliability of SaC has also been proven to be closely related to SeC (O'connor et al., 1989) which has been the common analyte of choice since the 1970s (El-Farhan et al. 2017).

There were further variations regarding the degrees of freedom allowed in relation to hormonal testing. Studies varied in their level of detailedness when describing the process of hormonal sampling. For instance, Born et al. detailed the time of testing, the participants's activity prior to sampling i.e., not eating, not drinking anything other than plain water and not brushing their teeth 30 minutes before, and how to sit when sampling (2017). Each of these aspects are considered due to their possible effect of hormonal levels or the sampling process within itself. In particular, time of testing may indeed influence cortisol levels considering its known diurnal variations. Contrairily, some studies were lacking contextual hormonal sampling information such as sampling environment or time of the day (exemplified by Bresciani et al. (2018)).

Figure 10. Number of assessments for each hormonal measure



5.2.3 Population descriptives

5.2.3.1 Sex

From the total of 47 studies, 23 were targeted toward males (48.9%), 11 toward both males and females (21.3%), 10 toward females (23.4%) and three did not report sex at all (6.4%) (see Figure 11). One study of both male and female subjects did not report the ratio of male to female participants. This left 44 studies with a total of 1234 participants with their sex reported. 656 were reported as male (53.2%) and 578 were reported as female (46.8%) (see Figure 12). To conclude, most studies are aimed towards a male population who are also in majority in the total number of participants studied. However, the ratio of male to female participants was not as big when assessed in the total number of participants studied. Therefore, the results could still be generalizable to both sexes.

Figure 11. Illustration of the study specific sex distribution

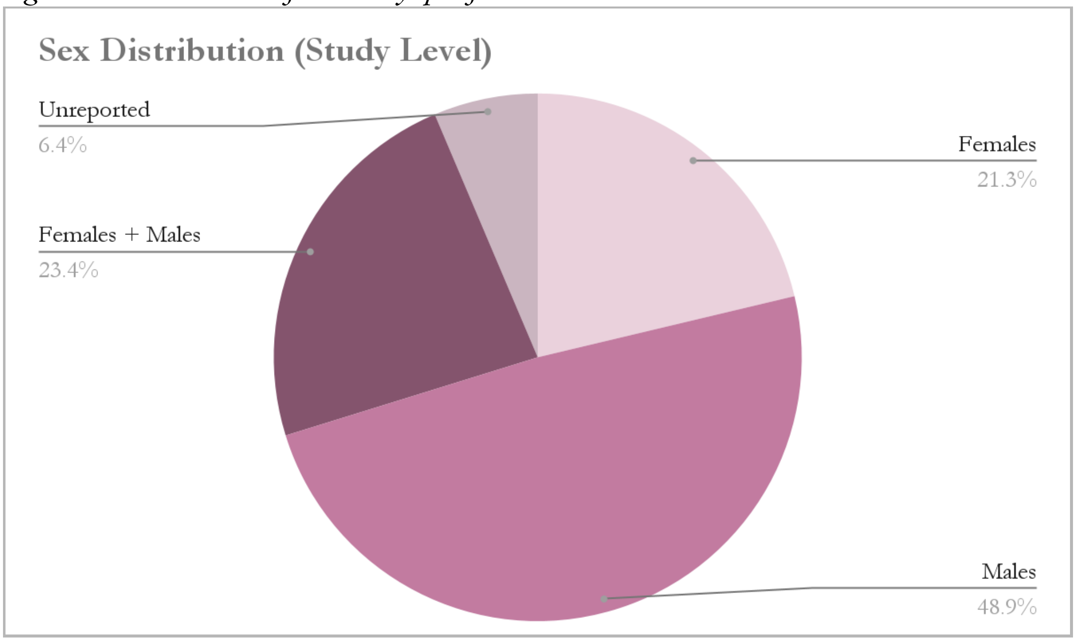
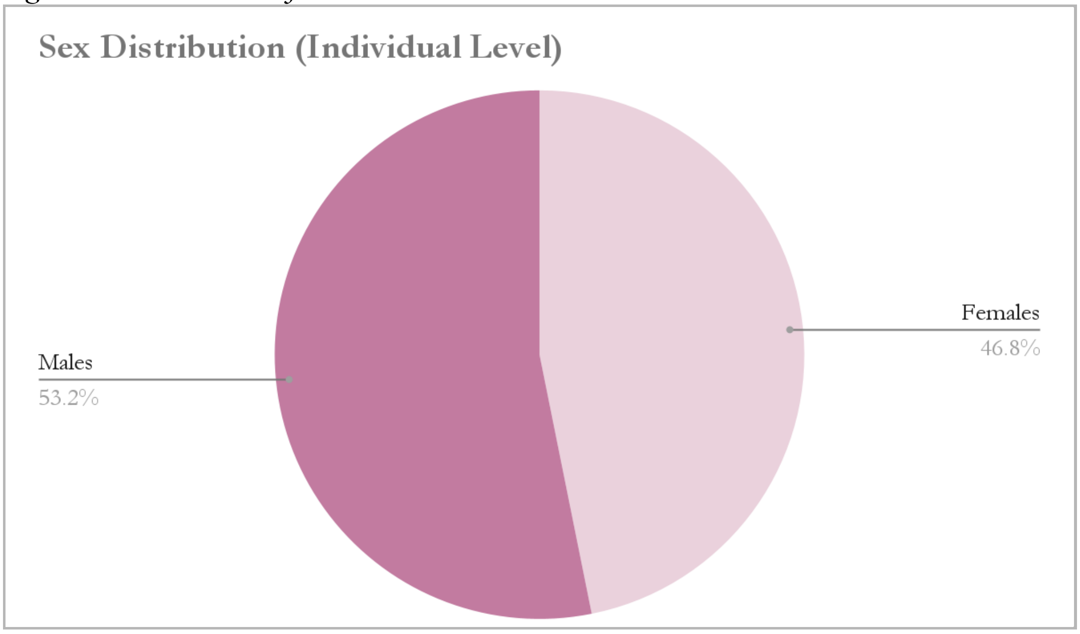


Figure 12. Illustration of total sex distribution

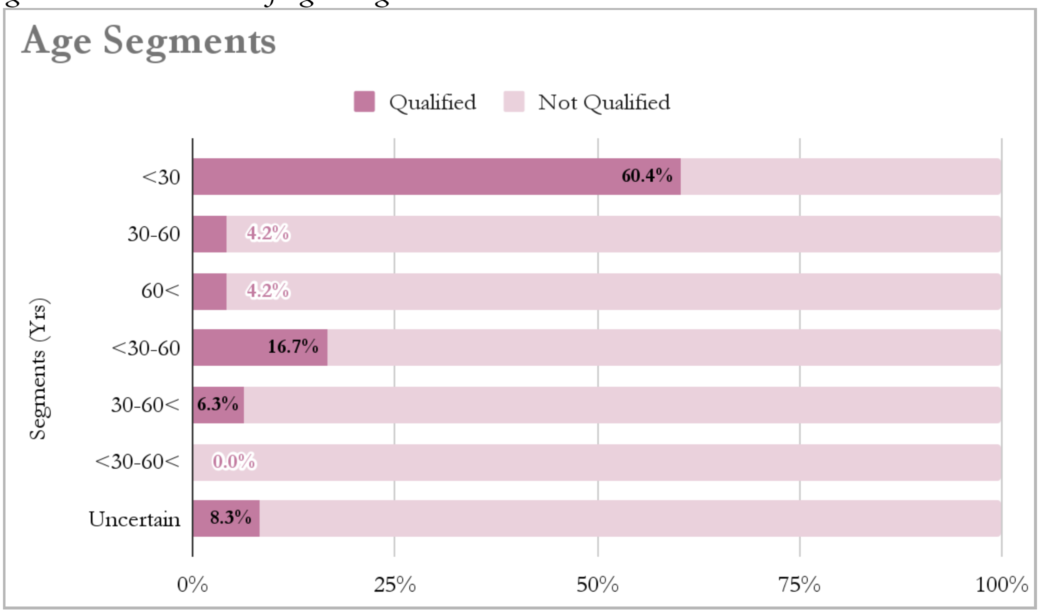


5.2.3.2 Age

Most of the studies were aimed towards populations with an age range exclusively below 30 years (60.4%). 8 studies (16.7%) populations included two age ranges in their study population, below 30 years as well as between 30 to 60 years (see Figure 13). Three studies' age range was reported as unknown since 1 only reported mean age (Harte et al. 1995) and 2 didn't report any age at all (Tharp et al. 1989, O'Connor et al. 1989).

Conclusively, more studies of individuals above 30 are needed to be able to generalise the results to older and middle-aged populations. At present, the analyses performed, and the results of this review mainly refer to young adults.

Figure 13. Illustration of age ranges included in the studies



5.3 Categorical study analyses

5.3.1 Acute exercise effects

Ten studies were identified as examinations of acute exercise effects (see Table 1).

Nine studies reported significant mood changes following exercise. Studies 1, 4, 5, 7, 8, 9 and 10 (70.0%) reported an increased presence of negative mood states following exercise. In studies 1, 4 and 8 this was a result appearing across multiple subscales. Studies 4 and 5 recorded concurrently improved mood states (see Table 1). Specific differences could be seen in study 4 showing improved mood from pre-exercise to 30 minutes post-exercise regarding tension and depression as well as improved mood regarding fatigue and confusion specifically from post-exercise to 30 minutes post-exercise. Study 2 reported exclusively improved mood states following exercise. Furthermore, the subscales of anger and depression were exclusively decreased or unaffected following exercise (see Table 1), meaning mood was rather positively than negatively affected across these subscales.

All studies reported a statistically significant change in measures of HPA axis-related hormones following exercise. Studies 1, 3, 4, 5, 6, 7, 8 and 9 (80.0%) reported significantly higher levels of either cortisol, ACTH or CRH after exercising (see Table 1). Study 10 reported the reverse results. Important to note is that the SaC levels pre-exercise were assessed early in the morning and post-exercise assessments were done after multiple hours of cycling (Slivka et al., 2010), subsequently, the effects of the diurnal variations might hide the response of the HPA axis following exercise.

In every study where SaC was used a statistically significant result was present. In study 7 both cortisol and CRH levels were assessed through plasma levels, but significant changes were only present of CRH (see Table 1). This could indicate a differently ruled relationship between cortisol and CRH to exercise. Furthermore, study 2 reported significantly increased levels of cortisol following exercise, mainly in older and male subjects, and did not observe a main effect of exercise (Sonnenblick et al., 2018).

Conclusively, exercise can acutely alter mood states both positively and negatively, however different subscales may be affected differently at different points following exercise. Furthermore, acute exercise can elicit a response of the HPA axis, particularly evident through the recorded increase of cortisol levels. Additionally, the response of the HPA axis might not be homogenous across all populations as it is suggested that older and male individuals can have a more pronounced response following exercise.

Table 1. Descriptives of studies categorised into Acute exercise effects.

Nr	Reference	Method	Span	Comparisons	Population	Mood	HPA axis
1	Howe et al., 2019	An 80.5 km treadmill ultra-marathon	<24h	Within (and between) groups	12 male and female endurance runners	POMS(TMD¤, Te, Dep, An, Vi¤, Fa¤, Co)	SeC¤
2	Sonnenblick et al., 2018	30min aerobic exercise	<24h	Within (and between) groups	60 male and female, younger and older participants	POMS(Te*, Dep*, An*, Vi, Fa*), VAS	SeC*
3	Loucks & Horvath, 1984	40min treadmill running	<24h	Within (and between) groups	8 female participants	POMS(TMD, Te, Dep, An, Vi, Fa, Co), STAI	PlC¤
4	Martínez-Díaz & Carrasco, 2021	A 20min HIIT intervention	<24h	Within groups	25 male active participants	POMS(iPOMS¤, Te*, Dep*, An, Vi, Fa¤*, Co¤*)	PlC¤, PlACTH¤
5	Broodryk et al., 2020	An aerobic fatiguing test	<24h	Within groups	43 female soccer players	POMS(TMD, Te, Dep, An, Vi¤, Fa, Co*, STAI(AA, AP*)	SaC¤
6	Butki & Rudolph, 2001	20min treadmill running at 85% maximal heart rate	<24h	Within (and between) groups	12 male physically active subjects	STAI*	SaC¤
7	Harte et al., 1995	A 15km outdoor run	<24h	Within (and between) groups	12 male elite distance runners	E-R¤, VAS(Pa*, Na*)	PlCRH¤, PlC
8	Broodryk et al., 2017	An anaerobic fatiguing test	<24h	Within groups	47 female soccer players	POMS(TMD¤, Te, Dep, An, Vi¤, Fa¤, Co¤), STAI	SaC¤
9	Sparkes et al., 2018	A 2h small-sided game soccer training	24h	Within groups	16 male soccer players	BAM+¤	SaC¤
10	Slivka et al., 2010	A cycling tour over 21 days	21 days	Within groups	8 male cyclists	POMS(TMD, Te, Dep, An, Vi¤, Fa, Co)	SaC*

* *Significant change following exercise*

¤ *Significant increase of the HPA axis activity or worsened mood state following exercise*

5.3.2 Effects of exercise condition

Three studies were identified as comparisons of different exercise conditions (see Table 2).

All three studies reported a significant change of mood following exercise. Studies 11 and 13 (66.7%) reported significant differences in mood between different conditions of exercise. In study 11, this was evident across the total mood disturbance and fatigue levels, and across subscales tension, depression, anger, vigour and fatigue in study 13 (see Table 2).

All three studies reported a significant change in HPA axis activity following exercise, measured by assessing cortisol levels. Studies 11 and 13 (66.7%) recorded significantly different changes in HPA axis activity across the different conditions of exercise (see Table 2). The results of study 11 were however preceded by a statistically significant difference between subjects at baseline and the following difference in cortisol levels was only present during the first three weeks of training (Sarabia et al., 2015).

Conclusively, different types of exercise may yield different acute effects in mood state and cortisol levels. Study 12 only altered training order and subsequently found no significant differences in the relevant variables between conditions. As study 13 altered the training environment and attentional focus and found comprehensive differences regarding mood and hormonal activity, indications suggest that the environmental and attentional stimuli could be further included as a relevant aspect in the relationship between PA, mood and the HPA axis.

Table 2. Descriptives of studies categorised to Effects of different exercise conditions

Nr	Reference	Method	Span	Comparisons	Population	Mood	HPA axis
11	Sarabia et al., 2015	Regular tennis practice vs. tennis practice + resistance training	6 weeks	Between subjects, within groups	20 male junior tennis players	POMS(TMD¤, Te, Dep, An, Vi, Fa¤, Co)	SaC¤
12	Sparkes et al., 2020	Training order manipulation of a small-sided-game and resistance training	24h x2	Within groups	14 male semi-professional soccer players	BAM+*	SaC*
13	Harte & Eifert, 1995	Environment and attentional-focus manipulation during running	45min sessions x4	Within groups	10 male endurance athletes	POMS(Te¤, Dep¤, An¤, Vi¤, Fa¤, Co)	UrC¤

* *Significant change following exercise*

¤ *Significant difference in results recorded between different exercise conditions*

5.3.3 Effects of training load

23 studies were identified as examinations of the effect of training load. Five studies tested the effects of training load within cycle training, four studies within swim training, five studies within run training, three studies row training, two studies within basketball training and four additional studies tested the effects of varying training load in varied sport settings.

5.3.3.1 Cycling

Study 14, 15, 17, and 18 reported significant changes in mood state between conditions. Each of them indicated a lowered mood state in conditions of higher training load compared to conditions of lower training load. In study 14 and 17 this was a consistently appearing result across multiple dimensions. Study 18 had mixed results across mood dimensions with only lowered mood state recorded in the decrease of vigour after intensified training (Filaire et al., 2011).

Studies 15-18 reported significant changes in HPA axis activity between conditions, through measures of SaC and SeC. Each of them indicated increased cortisol levels in conditions of higher training load compared to conditions of lower training load. Study 14 which used PlC for its hormonal assessment found no significant effects (see Table 3).

Table 3. Descriptives of studies categorised to the subcategory Cycling within the category of Effects of training load

Nr	Reference	Method	Span	Comparisons	Population	Mood	HPA Axis
14	Piacentini et al., 2016	Cycle training of varying intensity	3 weeks	Within groups	8 cyclists	POMS(GMS¤, Te¤, Vi¤, Fa¤)	PlC
15	Zehsaz et al., 2011	Cycle training of varying intensity	11 weeks	Between groups	24 male cyclists	POMS¤	SeC¤
16	Filaire et al., 2002	4 days of increased training load	4 months	Within groups	12 cyclists	POMS(OMS, Te, Dep, An, Vi, Fa, Co)	SaC¤
17	Bouget et al., 2006	Rapid increment of training load	4 days	Within groups	12 female cyclists	RESTQ-S(GS, ES¤, SS¤, C/P, F¤, LE, PC)	SaC¤
18	Filaire et al., 2011	Cycle and other training of varying load	8 months	Within groups	12 male cyclists	POMS(OMS*, Te,* Dep, An,* Vi,¤ Fa, Co)	SaC¤

* *Significant difference in results recorded between different exercise conditions*

¤*Significant difference between conditions with higher training load eliciting lower mood states or higher HPA axis reactivity compared to conditions of lower training load*

5.3.3.2 Swimming

Study 19-22 reported a significant change in mood state between conditions. Studies 20-22 indicated a lowered mood state across multiple dimensions in conditions of higher training load compared to conditions of lower training load (see Table 4). Contrarily, study 19 reported the opposite result through an increased presence of vigour during intensified training (Santhiago, et al., 2011).

Study 19 and 22 reported a significant change in HPA axis activity between conditions, through measures of SaC and SeC. Both indicated increased levels of cortisol in conditions of higher training load compared to conditions of lower training load (see Table 4).

Table 4. Descriptives of studies categorised to the subcategory Swimming within the category of Effects of training load

Nr	Reference	Method	Span	Comparisons	Population	Mood	HPA Axis
19	Santhiago et al., 2011	Swim training of varying intensity	14 weeks	Within groups	10 female elite swimmers	POMS(TMD, Te, Dep, An, Vi*, Fa, Co)	SeC¤
20	Vacher et al., 2019	Swim training of varying training load	12 weeks	Within groups	15 male and female swimmers	RESTQ-S(GS¤), SEQ(Anx¤, Ann¤, De¤, Ha¤, Ex¤)	SaC
21	O'Connor et al., 1991	4 days of intensified swim training, swim tests	4 days	Within groups	40 male and female swimmers	POMS(OMS¤, Te, Dep, An, Vi¤, Fa¤, Co)	SaC
22	O'Connor et al., 1989	Swim training of varying intensity, comparisons to physically active controls	5.5 months	Between and within groups	22 female subjects (swimmers *n*=14)	POMS(GM¤, Te¤ Dep¤, An¤, Vi¤, Fa¤, Co)	SaC¤

* *Significant difference in results recorded between different exercise conditions*

¤*Significant difference between conditions with higher training load eliciting lower mood states or higher HPA axis reactivity compared to conditions of lower training load*

5.3.3.3 Running

Study 23, 24, 25 and 27, reported a significant change in mood state between conditions. Each of them indicated a lowered mood state in conditions of higher training load compared to conditions of lower training load. In study 23 and 24 this was a consistently appearing result across multiple dimensions. Study 25 and 27 found lowered mood state only through one subscale each, fatigue and negative feelings respectively (see Table 5).

Study 24 and 27, reported a significant change in HPA axis activity between conditions. Both of them indicated increased cortisol levels in conditions of higher training load compared to conditions of lower training load and both of them used SeC for the hormonal assesment. Study 23 which did show a decremented mood state in the condition of higher intensity did not report concurrent increases in cortisol levels, as assessed by PlC (see Table 5).

Table 5. Descriptives of studies categorised to the subcategory Running within the category of Effects of training load

Nr	Reference	Method	Span	Comparisons	Population	Mood	HPA Axis
23	Bresciani et al., 2011	Running of varying intensity	12 weeks	Within groups	9 male, active subjects	POMS(TMD¤, Te¤, Dep, An, Vi, Fa¤, Co¤), RESTQ-S(GS¤), STAI¤	PlC
24	Verde et al., 1992	Running of varying intensity/distance	6 weeks	Within groups	10 male distance runners	POMS(GM¤, Te, Dep, An, Vi¤, Fa¤, Co)	SeC¤
25	Tanaka et al., 1997	Run training of varying volume	6 weeks	Within groups	10 male distance runners	POMS(GMS, Te, Dep, An, Vi, Fa¤, Co)	SeC
26	Born et al., 2017	Running of varying intensity	3 weeks	Between and within groups	28 male endurance runners	St, Anx, Ann, Ha, Exh, En	SaC
27	Uusitalo et al., 1998	Exercise of varying intensity, mainly running	15 weeks	Between and within groups	15 female endurance-trained athletes	PF, NF¤	SeC¤

¤*Significant difference between conditions with higher training load eliciting lower mood states or higher HPA axis reactivity compared to conditions of lower training load*

5.3.3.4 Rowing

Studies 28-30 reported a significant change in mood state between conditions, indicating a lowered mood state in conditions of higher training load compared to conditions of lower training load. In study 30 this was a consistently appearing result across multiple subscales. Studies 28 and 29 found lowered mood state only through one measure each, energetic arousal and fatigue respectively (see Table 6).

Only study 29 reported a significant change in HPA axis activity between conditions, through measures of PlC, indicating increased cortisol levels in conditions of higher training load compared to conditions of lower training load. Studies 28 and 30, which did show decremented mood states in conditions of higher training load, did not report concurrent increases in cortisol levels, as assessed by SeC and SaC (see Table 6).

Table 6. Descriptives of studies categorised to the subcategory Rowing within the category of Effects of training load

Nr	Reference	Method	Span	Comparisons	Population	Mood	HPA Axis
28	Krokosz et al., 2014	High intensitivity row training	8 weeks	Within groups	10 male rowers	UMACL(EA, TA, HT)	SeC
29	Jürimäe et al., 2002	Rapid increment of training load	6 days	Within groups	10 male junior rowers	RESTQ-S(GS, ES, SS, C/P, F¤, LE, PC)	PlC¤
30	Shields et al., 2017	Row training of varying intensities, comparisons to controls	5 months	Between and within groups	66 male and female subjects (rowers *n*=43)	POMS(TMD¤), PSS¤	SaC

¤ *Significant difference between conditions with higher training load eliciting lower mood states or higher HPA axis reactivity compared to conditions of lower training load*

5.3.3.5 Basketball

Study 32 reported a significant mood change, between conditions (see Table 7). This was in the form of a higher score of vigour in a team with a lower training load (González-Bono et al., 2002).

Both studies reported a significant change in HPA axis activity between conditions, through measures of cortisol. Each of them indicated increased cortisol levels in conditions of higher training load compared to conditions of lower training load (see Table 7). In study 32 there were however different scores already at baseline (González-Bono et al., 2002).

Table 7. Descriptives of studies categorised to the subcategory Basketball within the category of Effects of training load

Nr	Reference	Method	Span	Comparisons	Population	Mood	HPA Axis
31	Salvador et al., 2002	Basketball training of varying volume, cycle ergometer tests	4 months	Between and within groups	20 male basketball players	POMS(POMS-t, Te, Dep, An, Vi, Fa, Co)	SeC¤, PlC¤
32	González-Bono et al., 2002	Basketball training of varying volume, cycle ergometer tests	4 months	Between and within groups	18 male basketball players	POMS(POMS-t, Te, Dep, An, Vi¤, Fa, Co)	SaC¤

¤ *Significant difference between conditions with higher training load eliciting lower mood states or higher HPA axis reactivity compared to conditions of lower training load*

5.3.3.6 Mixed

Studies 33-36 reported a significant change in mood between conditions. Study 34 and 35, indicated a lowered mood state in conditions of higher training load compared to conditions of lower training load. In study 34 this was a consistently appearing result across multiple scales (see Table 8). Study 35 reported a mixed result with both improvements and decrements of mood state following higher training intensities (Arent et al., 2005). Contrary to study 34, study 33 reported significantly higher scores of anger and general stress before than during the implementation of the most intensive exercise (Stephenson et al., 2019)

Studies 34-36 reported a statistically significant change in HPA axis activity between conditions, through measures of cortisol. Each of them indicated increased cortisol levels in conditions of higher training load compared to conditions of lower training load (see Table 8), however, in study 34 this result was only evident in the evenings during a taper period (Papacosta et al., 2013).

Table 8. Descriptives of studies categorised to the subcategory Mixed within the category of Effects of training load

Nr	Reference	Method	Span	Comparisons	Population	Mood	HPA Axis
33	Stephenson et al., 2019	Training program with varying intensity	5 weeks	Within groups	10 male and female elite para-triathletes	POMS(TMD, Te, Dep, An*, Vi, Fa, Co), RESTQ-S(GS*)	SaC
34	Papacosta et al., 2013	Judo training of varied volume	5 weeks	Within groups	11 male judo athletes	POMS(TMD¤, Te¤, De¤, An¤, Vi, Fa¤, Co¤), VAS(GF¤)	SaC¤
35	Arent et al., 2005	Weight training of varying intensity	<24h x4	Within groups	31 male and female active participants	AD-ACL(EN*, TI*, TE¤, CA*), PANAS(PA*, NA*¤), STAI*	SaC¤
36	Sparkes et al., 2020	A single vs a double training session of SSG	24h x2	Within groups	12 male semi-professional soccer players	BAM+*	SaC¤

** Significant difference in results recorded between different exercise conditions*

¤Significant difference between conditions with higher training load eliciting lower mood states or higher HPA axis reactivity compared to conditions of lower training load

To conclude the data from the 23 studies in the category *effects of training load,* 20 of the studies (87.0%) reported a statistically significant change in mood state between conditions. 17 of the studies (73.9%) indicated a lowered mood state in conditions of higher training load compared to conditions of lower training load.

14 of the studies (60.1%) reported a statistically significant change in HPA axis activity between conditions. Each of them indicated increased cortisol levels in conditions of higher training load compared to conditions of lower training load.

Conclusively, a mixed response due to variations of training load was found in both mood state and HPA axis activity. Mood was majoritively more negatively affected by higher training loads compared to lower training loads. There were however variations of consistency across scales with some studies concurrently or exclusively reporting improved mood as an effect of a higher training load. HPA axis activity was also majoritively more affected by higher training loads compared to lower training loads with an increase of cortisol levels, although not as consistently appearing as the increments of mood states. No clear pattern emerges in terms of which method of hormonal assessment concurs with significant results.

5.3.4 Physical activity level's effect on mood and the HPA axis

Two studies were identified as studies of PA level's effect on mood and HPA axis activity (see Table 9).

Study 37 found a significant difference between groups where participants with a higher activity level presented more positive mood states compared to less active participants (see Table 9).

Neither study found any significant differences in HPA axis activity as determined by PA level (see Table 9).

Conclusively, when PA level is assessed over a longer period of time (e.g. 1 year), differentiated mood profiles can be evident between more and less active individuals, with more PA being concurrent with more positive mood states. Furthermore, the results do not support that regular PA as measured over a shorter period (e.g. 4 days) will significantly impact mood. Lastly, the effect on HPA axis activity in an untriggered state (as both studies sampled SaC at rest (Ariza-García et al., 2013; Strahler et al., 2019)), even in a population with stable differences in PA, did not reach significant differences between groups.

Table 9. Descriptives of studies categorised to Physical activity level's effect on mood and the HPA axis

Nr	Reference	Method	Span	Comparisons	Population	Mood	HPA axis
37	Ariza- García et al., 2013	Physical inactivity level (<3 METs × h/week) vs Adequate PA level (>3 METs × h/week)	1 year	Between groups	108 middle-aged female breast cancer survivors	POMS(TS¤, Te, Dep¤, An¤, Vi, Fa¤, Co¤)	SaC
38	Strahler et al., 2019	Minutes per day	4 days	Between and within groups	77 male and female subjects	MDBF, F/S	SaC

¤ *Statistically significant results where a higher degree of PA is concurrent with improved mood states compared to less PA*

5.3.5 Long-Term Intervention

Four studies were identified as examinations of long-term interventions (see Table 10).

All studies reported statistically significant changes in measures related to mood, indicating improved mood states. In study 39 and 42 this was a consistently appearing result across multiple subscales. Study 40 found positive effects through a decreased presence of depressive symptomatology following the exercise intervention (see Table 10).

Studies 39 and 41 (50%), reported significant changes in measures related to HPA axis activity. Both interventions indicated lowered HPA axis activity through measures of cortisol levels. Decreased levels of ACTH were however not concurrent with the decreased levels of cortisol (see Table 10).

Conclusively, a variety of interventions of exercise programs may likely have a positive effect on mood and may improve mood in participants suffering from mood disorders. The effect on HPA axis activity is however not as clear as significant changes were evident in half of the studies and oly regarding cortisol levels and not ACTH levels.

Table 10. Descriptives of studies categorised to Long-term interventions

Nr	Reference	Method	Span	Comparison	Population	Mood	HPA axis
39	Cho et al., 2016	Three 40 min aerobic exercise sessions per week	8 weeks	Between and within groups	24 female, middle-aged participants	POMS(Te¤, Dep¤, An, Vi¤, Fa¤, Co¤)	PlC *, PlACTH
40	Leone et al., 2018	Two 75 min resistance/ aerobic exercise sessions per week	8 weeks	Within group	7 participants affected by mood disorders	BDI¤	SaC
41	Tada, 2018	Two 20 min resistance exercise sessions per week	6 months	Between and within groups	61 older adults both male and female	POMS(Te, Dep, An, Vi, Fa¤, Co)	SaC*
42	Starkweather, 2007	Five 30 min walking sessions per week	10 weeks	Between and within groups	20 older adults both male and female	POMS(TMD¤), PSS¤	PlC

* *Statistically significant result in relevant variables*

¤ *Statistically significant change in relevant variables where mood states are improved or HPA axis activity is decreased after intervention*

5.3.6 Physical activity's stress-buffering effects

Five studies were identified as examinations of physical activities stress-buffering effects (see Table 11).

Four of the studies (80%) reported significant changes in mood states after exposure to stressor and significant differences between groups. Studies 46 and 47 (50%) indicated better mood states in more physically active subjects compared to less active subjects after exposure to a stressor. In study 46, significant differences were only found in

subscales regarding positive mood states between groups whereas all participants had an increased presence of negative affect. Study 43 cortrarily indicated better mood states in the less physically active subjects in comparison to the more active subjects after exposure to the stressor (see Table 11).
All five studies reported significant changes in HPA axis activity after exposure to the stressor. Studies 43, 45 and 47 (60%) reported statistically significant differences in cortisol levels between subjects with more active subjects showing lower cortisol levels compared to less active subjects (see Table 11). Study 44 found no main effect of PA level and instead indicated age as a determining factor where older subjects had a more pronounced cortisol reactivity (Gröpel et al., 2018). In study 46, male participants were also found to have a more pronounced response of cortisol when compared to the female participants (Childs & de Wit, 2014).

Conclusively, a more physically active lifestyle can aid in the response to psychosocial stressors, particularly when compared to sedentary or untrained individuals but a surefast relationship is not observed as one study reached the opposite result. The results of study 44, which indicated non-significant differences between participants' stress response, should cautionarily be interpreted as evidence against the notion that trained individuals are more adept at handling stressors as both groups already obtained active lifestyles (Moya-Albiol et al., 2001). Lastly, all participants in each of the studies (though study 43 reported some non-responders regarding cortisol reactivity (Klaperski et al., 2013)) are affected by the stressors through increased HPA axis activity but trained individuals do show an attenuated response.

Table 11 Descriptives of studies categorised to Physical activity's stress-buffering effects

Nr	Reference	Method	Comparisons	Population	Mood	HPA axis
43	Klaperski et al., 2013	Psychosocial stressor, 0h exercise per week vs 3h> exercise/week	Between and within groups	47 female participants	MDBF(G-BM*, C-N*), STAI*	SaC¤
44	Gröpel et al., 2018	Psychosocial stressor, endurance-trained vs resistance-trained vs untrained subjects	Between groups	34 male participants	PANAS(PA, NA*)	SaC*
45	Moya- Albiol et al., 2001	Physical stressor, elite sportsmen vs subjects moderately active ≤ 5 days/week)	Between and within groups	26 male participants	STAI	SaC¤
46	Childs & de Wit, 2014	Psychosocial stressor, exercising ≥1 times per week vs exercising 0 times per week	Between and within groups	111 male and female participants	POMS(PM¤(Fr¤, El¤), NA*(Anx*, De*, An*, Co*)	SaC*
47	Rimmele et al., 2006	Psychosocial stressor, elite sportsmen vs inactive subjects	Between and within groups	44 male participants	MDBF(G-BM*, C-N*), STAI*	SaC¤

* *Statistically significant differences either between subjects or within subjects*
¤ *Statistically significant difference between subjects with more physically active subjects showing a better mood or an attenuated HPA axis response compared to less physically active subjects after stress exposure*

5.4 Results from correlational analyses

15 out of the 47 identified studies (31.9%) reported results of correlational tests between measures relating to mood and HPA axis-related hormones. 10 out of these 15 studies (68.8%) found significant correlations. Eight out of the 16 studies (50.0%) also included the results of non-significant correlations. All results of the reported correlational analyses are depicted in Table 12.

Correlations between SaC and mood were tested in nine studies. It correlated positively to scores of anxiety in study 5 and 6. SaC also correlated positively to scores of vigour before exercising in study 32 (González- Bono et al., 2000), and scores of depression after excessive exercise in study 22 (O'Connor et al., 1989). There were also reported results of non-significant correlations of SaC to mood in six of the nine studies (66.7%) where it was tested.

Correlations between PlC and mood were tested in three studies. In study 4 it negatively correlated to scores of vigour pre-exercise and positively to scores of fatigue post-exercise. It also correlated negatively to the calculated iPOMS score post-exercise and positively to scores of confusion, 30 minutes post-exercise (Martínez- Díaz & Carrasco, 2021). In study 29, when assessed at rest during periods of intense exercise, PlC positively correlated to scores of fatigue and social stress (Jürimäe et al., 2002). Lastly in study 42, PlC was positively correlated to perceived stress. No study explicitly reported any non-significant relationships between PlC and mood.

Correlations between SeC and mood were tested in two studies. In study 2 it correlated negatively to scores of vigour post-exercise and positively to the changes of fatigue scores (Sonnenblick et al., 2018). In study 28, no significant correlations were found between SeC and mood.

Correlations between PlACTH and mood were only tested in study 4. Pre-exercise, a negative correlation to scores of vigour was found. Post-exercise, a positive correlation was evident between PlACTH and scores of fatigue and confusion as well as a negative correlation to the calculated iPOMS score.

Lastly, study 7 tested correlational relationships between PlCRH and mood. A positive relationship was found between PlCRH and positive affect.

Conclusively, tests of correlation between the HPA axis related hormones and mood states are not often performed. When conducted, limited support is found for the cross-stressor adaptation hypothesis due to the number of non-significant results being present in the studies reportation. The existence of non-significant results is possibly even greater as not all studies explicitly stated which correlational tests had been conducted, other than those in which a statistically significant result had been reached. One could however conclude that, due to the differences in the studies of when and if a significant correlation is present following PA, the relationships between the HPA axis and different mood states are dependent on different physiological states of exertion. For instance, vigour was reported to negatively correlate to SeC before engaging in exercise and depressive mood was only correlated to SaC following intense exercise. Lastly, as cortisol and ACTH levels have yet to be positively correlated to improved mood states it is more likely that higher HPA axis activity, specifically in regard to cortisol and ACTH, will be concurrent with negative mood states compared to positive mood states. Also noteworthy is the observed reverse relationship between CRH and a positive mood state.

Table 12. Table of studies that reported their results of correlational analyses between measures relating to mood and measures relation to the HPA axis

Nr	Reference	Correlational analysis
2	Sonnenblick et al., 2018	SeC-Vi¤, SeC-Fa¤
4	Martínez- Díaz & Carrasco, 2021	PlACTH-Vi¤, PlACTH-iPOMS¤, PlACTH-Co¤, PlC-Fa¤,PlC-iPOMS¤, PlC-Co¤
5	Broodryk et al., 2020	SaC-AA¤, SaC-TMD, SaC-Te, SaC-Dep, SaC-An, SaC-Vi, SaC-Fa, SaC-Co, SaC-AP
6	Butki & Rudolph, 2001	SaC- STAI¤
7	Harte et al., 1995	PlCRH-PA¤
8	Broodryk et al., 2017	SaC-TMD, SaC-Te, SaC-Dep, SaC-An, SaC-Vi, SaC-Fa, SaC-Co, SaC- STAI
16	Filaire et al., 2002	SaC-OMS, SaC-Te, SaC-Dep, SaC-An, SaC-Vi, SaC-Fa, SaC-Co
18	Filaire et al., 2011	SaC-OMS, SaC-Te, SaC-Dep, SaC-An, SaC-Vi, SaC-Fa, SaC-Co
22	O'Connor et al., 1989	SaC-Dep¤
28	Krokosz et al., 2014	SeC-UMACL, SeC-EA, SeC-TA, SeC-HT
29	Jürimäe et al., 2002	PlC-SS¤, PlC-Fa¤
32	González- Bono et al., 2002	SaC-Vi¤
41	Tada, 2018	SaC-Fa
42	Starkweather, 2007	PlC-PSS¤
47	Rimmele et al., 2006	SaC-G-BM, SaC-C-N, SaC-STAI

¤ *Statistically significant correlation*

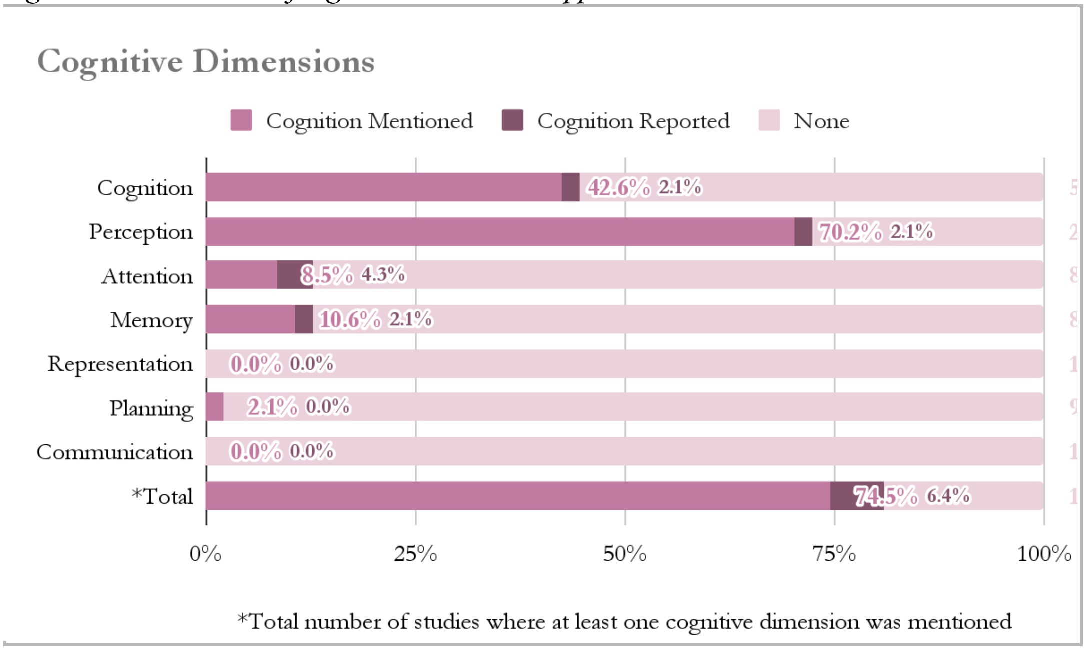
5.5 Cognitive Dimensions

5.5.1 Cognition mentioned

35 studies (74.5%) mentioned cognition as a field of inspiration or possible influence. Perception was considered in 33 (70.2%) of the studies, cognition was considered in 20

(42.6%) of the studies, memory in 5 (10.6%) of the studies, attention in 4 (8.5%) of the studies. Representation, planning and communication was considered in one study each (see Figure 14). A large portion of the studies involved the perception dimension where it was often described as part of a rating test where the participants got to score their first-person experience of affective states (Verde et al., 1992).

Figure 14. Illustration of cognitive dimension appearance



5.5.2 Cognition studied

Three studies (6.4%) explicitly reported tests of cognitive performance. Explicitly reported refers to studies where a separate cognitive condition was measured and reported. Study 13 investigated the effects of running environment and attentional focus. Attention directed toward internal phenomena (exemplified by headphones giving feedback of one's breathing) was implemented during a treadmill run compared to an outdoor run and an additional treadmill run with attention directed toward external phenomena. The internal focus produced higher levels of tension, depression and anger when compared to the external focus (Harte & Eifert, 1995).

Study 27 examined how both the level of cortisol and mood can modulate cognitive functioning (Krokosz et al. 2014). They analysed this relationship by examininging attention divisibility among athletes, comparing subjectively perceived moods and their blood levels of cortisol during high intensity training and reported a negative correlation between mood and attention divisibility.

Study 29 assessed whether perceived or behavioural aspects of cognition changed over the course of a season of a competitive season in student-athletes. Simple effects within the group demonstrated significant differences in perceived cognitive deficits during peak training compared with the other training loads. The student-athletes reported significantly higher PDQ (Perceived Deficits Questionnaire) scores during peak training compared with a control group. Cognitive function, assessed by the Stroop colour-naming task, did however not change over the course of the season.

Conclusively, attentional focus may affect the experience of exercise, producing diverse effects on mood states. Changes in mood may be able to affect performance in an attention-divisibility test and periods of high training load can produce perceptions of cognitive deficits.

6 Discussion and conclusions

6.1 Aims and results

Through this review, the aim was to examine the existing research of PA's effect on mood and HPA axis activity. Through the examination, the hopes were to confirm the existence of a paradoxical relationship between PA, mood and the HPA axis, dependent on: part 1) that following acute PA an increase of HPA axis activity co-occurs with a decremented mood state, and part 2) that after regularly exercising for a longer period of time a lower degree of HPA axis activity is concurrent an improved mood state, refering to research question 1. Additionally, the existence of a dose-respondent relationship between PA and the HPA axis, research question 2, and support for the cross-stressor adaptation hypothesis would be assessed, referring to research question 3. The 47 identified studies were also examined based on their methodological approaches, their study population and their reported results in hopes to answer research question 4. And lastly, due to cognition's connection to PA, mood and the HPA axis, the hopes were to examine if this connection was mirrored in the identified research and how it played out, research question 5.

6.1.1 The paradoxical relationship

Acute exercise and high training loads of exercise had majoritively negative significant effects on mood. Acute exercise and high training loads also significantly increased the levels of HPA axis related hormones in most of the studies. These results do somewhat support part 1 of the paradoxical relationship between PA's effect on mood and the HPA axis and that the response of the HPA axis following PA is dose-respondent.

When PA level was assessed over longer periods of time (e.g., > 4 days) and there were large enough differences in participants' PA levels when compared, results mainly indicated more positive mood states in more physically active participants and lower reactivity of HPA axis related hormones when exposed to stressors. Most of the long-term interventions of training programs also produced improvements in mood states and some did show decreased levels of HPA axis-related hormones. These results do somewhat support part 2 of the paradoxical relationship between PA 's effect on mood and the HPA axis.

Withal, these conclusions should not be drawn without the notation that when examining each individual study, PA did not always produce a significant change in the related hormonal levels, a dose-respondent relationship was not always evident, and mood was not always concurrently negatively altered. The results also suggest that the response of the HPA axis might not be homogenous across all populations, as older males were reported to have a more solid response of the HPA axis following exercise. Additionally, the specific time of measuring relating to the PA performed with variations in only minutes may determine the possible observable effects on mood. The results therefore only partly reconfirm the paradoxiacal relationship, only partly support a dose-respondent relationship between PA an HPA axis activity and therefore highlights a need for further detailed analyses, regarding research question 1 and 2.

6.1.2 The Cross-stressor adaptation hypothesis and correlational analyses

Regarding research question 3, a minority of studies (31.9%) reported tests of the relationship between HPA axis related hormones and mood. By analysing the results of those who did report correlational analyses, the result was inconclusive. For the cross-stressor adaptation hypothesis to be either accepted or rejected, additional analyses of correlational relationships could prove useful, as well as regressional analyses which would provide insight regarding the causality of the relationship. The preliminary analysis of this review does however not yield support for the hypothesis to be true as the result then would be expected to show significant correlations more consistently. There does appear to be an additional layer of complexity, ruling when and how fluctuations of hormonal levels concurs with altered mood states, namely the state of exertion. This conclusion is based on the specificity of significant correlations only being present at certain points during the studies testing periods (e.g., pre-exercise, post-exercise, 30 min post-exercise).

6.1.3 Methodological considerations

Regarding research question 4, the results suggest that there may be an added complexity in asseing mood and HPA axis activity and that the population of choice may indeed impact the results.

6.1.3.1 Quantification of mood

Even though the results of the studies mostly indicated the expected effects of exercise on mood, the responses did differ across the multiple subscales of mood included in the analysis. Improved mood was found in some subscales following acute exercise (studies 2, 4 and 5 (see Table 1)). Positive mood was also reported in some subscales in conditions of higher training load compared to conditions of lower training load (studies 18, 19, 33 and 35 (see Table 3, 4 and 8)). These results point to the complexity of mood and its quantification. Mood is multidimensional and should therefore be assessed as such. Studies including only a single measure of mood state or adding the scores of multiple subscales and only reporting a total score, risk presenting inaccurate results. Furthermore, with the 12 different mood questionnaires and the additional variation within each of them, an issue arises in the comparability of the mood changes observed between studies

6.1.3.2 Assessment of the HPA axis

Salivary cortisol was the most common way of measuring HPA activity and was often the only HPA measurement. Only 4 of the studies (8.5%) used multiple sampling methods which may be disadvantageous as half of these studies (7 and 39) reported differentiated results between their hormonal measures. Using multiple measurements could therefore be discussed as a way to improve the reliability of the results and get a more detailed view of the response of the HPA axis. Moreover, the hormones, though ACTH and CRH were sparsely measured, showed different relationships regarding mood where CRH was concurrent with positive mood, contrary to cortisol and ACTH.

The comparability of results between studies is furthermore complicated due to the allowed degrees of freedom through some of the studies hormonal sampling. Additionally, as there is an increased risk of confounding stress-induction by invasive methods (Marques et al. 2010), such as serum and plasma sampling, comparability between aforesaid methods and salivary sampling could be reduced.

6.1.3.3 Population

6.1.3.1 Sex

When comparing males against females there's a gap where all male-focused studies constitute 48.9% of the studies while the equivalent for females only reaches 23.1%. One possible explanation, as mentioned in some of the studies, is the effects of the female menstrual cycle. Specifically, the luteal phase affects the hormonal balance which is said to influence fatigability during exercise (Pereira, 2020). However, it's not sure that this affects the connection between exercise and mood significantly. Rather, daily physical health status, perceived stress and social support has proven to explain daily mood better than menstrual cycles (Romans, 2013). With this in consideration, the gap between male-and-female focused studies may be less justifiable. Furthermore, even though the total number of participants studied were almost equally divided between male and female participants and the results of this review therefore could be deemed generisable for both male and females, males were still in majority. Paired with the observed greater response in males of cortisol reactivity, the results may not as accurately represent the reactivity of the HPA axis regarding of a female population.

6.1.3.2 Age

Out of the age segments categorised and analysed through this review a large majority (60.4%) of studies exclusively included populations under 30 years of age. Paired with the further indications that age does matter in regard to the relationship between PA, mood and the HPA axis an issue arises regarding the generalisability of the results. Other studies have also shown that a higher age entails a less flexible physiological stress response accompanied with a reduced homeostasis ability (Charles, 2010; Seeman et al., 2010). Cortisol levels are up to 50% lower among individuals aged 20 compared to those aged 80 years (van Cauter et al., 1996). Interestingly Traustadóttir et al. found that younger fit women displayed similar level of cortisol responses as older fit women which hints that PA may protect older adults from cumulative and negative effects of cortisol dysregulation by positive effects on the HPA axis activity stimulating the negative feedback and prevent further activation of the HPA axis (Zschucke et al., 2015). To make this field of research equally relevant for all age segments, and to be able to further discern the differences between these age groups, more studies with populations over the age of 30, as well as comparisons between different age groups are necessary.

6.1.4 Cognitive dimensions

Regarding research question 5, the cognitive dimensions have a shallow presence in most of the studies. It is often considered but rarely tested in combination with PA, mood and the HPA axis. Since the few studies that included cognition in the result did produce significant results, it would be interesting to further explore how cognition can influence the relationship. Furthermore as, study 13 tested the effects of running paired with manipulations of attentional focus and reached significant effects regarding multiple dimensions of mood (Harte & Eifert, 1995) cognition could be said to have a possible influence of the effects PA will have on mood.

6.2 Limitations of the review

Through this review, conclusions have largely been based solely on the existence of statistically significant results. No data was collected regarding effect size which could influence the interpretation of the results and allow for a more dexterous analysis.

Further, as all screenings of the articles and data extractions were done manually, some caution should be considered regarding the results of the review. Additionally, since no blind reviews were performed and the initial screenings were divided between the authours, the subjective interpretation of the studies could have influenced the reporting. However, at the later stages both authours thoroughly anlalysed the final studies included for the review.

The specific way of categorising and analysing the studies' results could also be questioned. Although the categorisation of each study which could be interpreted to belong to more than one category was cross referenced between the authors, the fact remains that some studies could be included in additional categories. For instance, study 45 which examined differentiated responses of a physical stressor between participants of varying PA level (see Table 11), could additionally be included in the 'acute exercise effects' category rather than just 'physical activity's stress-buffering effect'. The same applies to some studies from the categories 'effects of exercise conditions' and 'effects of training load'. Putting such studies in multiple categories or performing additional analyses within each category could have produced different conclusions.

Further critique could be aimed towards the choice to include "feeling" in the mood related search words as it can be argued that it is more directed towards shorter, more fleeting processes such as emotions rather than the more stable mood state. However, no study included in the analysis depended on the word 'feeling' for inclusion.

Moreover, the implemented definition of cognition and what processes it entails could be further critiqued as certain aspects of cognition could have been overlooked.

Lastly, the conclusions regarding the paradoxical relationship between PA, mood and the HPA axis, the cross- stressor adaptation hypothesis, and the possible influence of cognitive factors, are mostly applicable to a younger, male population as that is what most of the included studies were based on.

6.3 Future research

This review shows that further analysis of the relationship between PA, mood and the HPA axis is needed. It appears to be a complex field of study both by the multidimensionality of mood and the differentiated results of HPA axis- related hormones. Further, time of measurement of mood and the HPA axis-related hormones related to when the PA is perfomed and the demographics of the studied population may greatly alter what changes can be observed. These aspects should be further studied. It would be beneficial to perform further reviews and meta-analyses on a smaller scale, where the results would be more comparable between studies. The role of cognition should also be further analysed as an influencing factor, particularly regarding mood states.

6.4 Conclusions

The findings of this systematic literature review provide insights regarding the connection between PA, HPA axis and mood, indicating a very complex relationship with equally complex components. The multidimensionality of mood creates difficulties summating a score which can describe altered mood states adequately. Assessment of HPA axis activity might require more variations of measuring, as there were differentiated responses across the related hormones and differently directed correlational analyses to positive and negative mood states. Finally, the effects of PA do not produce equal responses for everyone, and indications suggest that either the time since exercising or the level of exertion may greatly alter which observable differences can be seen. There also seems to be additional relevant factors regarding the perception of exercising, indicating that cognition may alter the effects PA can have on mood.

The findings also bring a clarified overview to the study field regarding alignment, standardisation and representativity. For future expansion of this field of study further analyses should be performed but on smaller scales where results are more comparable.

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