Body Representation and Physical Activity: An Investigation into Body Representation and its Mechanism of Change

Dissertation

zur Erlangung des Grades eines
Doktors der Naturwissenschaften

der Mathematisch-Naturwissenschaftlichen Fakultät
und
der Medizinischen Fakultät
der Eberhard-Karls-Universität Tübingen

vorgelegt
von

Duangkamol Srismith
aus Chiang Mai, Thailand

2021

Tag der mündlichen Prüfung:	28.07.2021
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Contents

Abstract

How the body is represented constitutes a vital part in the construction of the sense of self and maintenance of an identity that is unique to each individual. Body representation is a multi-dimensional concept, which includes explicit body-related cognitions, as well as the processing of more unconscious bodily information. These underlying representations can be categorised along the perceptual versus cognitive-affective, and implicit versus explicit dimensions. In other words, the concept of body representation encompasses basic awareness of the bodily status and dimensions, as well as how individuals may think, feel, perceive, and act with regard to their own body. In thinking about the relationship between an individual and their body, its dual characteristic is notable. Not only do we act and interact with the outside world with our body, we also possess cognitions and enact behaviours that are relevant and directed to our own body as an object. During recent years, there has been an increasing interest in the investigation of different aspects of body representation. In particular, the underlying cognitive and neural mechanisms of body representation, as well as how such mechanisms might become disrupted in clinical populations. As yet, however, the overall mechanisms of change in body representation are still poorly understood. An important aspect that has been relatively under-researched is physical activity—since engagement in physical activity generates a lot of relevant sensory information that directly affects the body, which could in turn shape individuals' body-related cognitions. The main goal of the present dissertation is to investigate changes in body representation in the context of physical activity in a longitudinal context, with focus on a population of healthy adults who have been previously sedentary. We use an updated theoretical framework of body representation, as well as a multimethod account involving innovative methods to disentangle and evaluate changes in different facets of body representation as individuals undergo physical activity training, which include body size perception, body image, and interoception.

The dissertation consists of four sub-components. Study I describes the study protocol of the iReAct study—an interdisciplinary research network aimed at providing a biopsychosocial analysis of the individual response to physical activity—in which the current project is embedded. Study II provides a systematic review of longitudinal studies evaluating the effectiveness of physical activity intervention on improving body representation. Specifically, the review highlighted the need for future studies to consider expanding the theoretical framework to include other aspects of body representation beyond body image. Study III investigates the interrelations between individuals' affective response to physical activity and two facets of body representation: body image and interoception. Mediation analyses reveals that effects of physical activity on changes in body image post physical activity intervention are independent of individual differences in interoceptive abilities. Study IV provides a comprehensive assessment of body representation in healthy adult samples who routinely engage in high versus low levels of physical activity. Self-report cognitive-affective body image data was combined with experimentally derived parameters obtained via technologically innovative paradigms designed to assess body size perception (i.e., perceptual body representation), as well as interoceptive measures. In sum, the project provides a comprehensive characterisation of different domains of body representation across relevant subsets of the healthy population. It also yields first results on longitudinal changes in body representation and the potential mechanistic interplay between different underlying body-related representations in the context of physical activity.

Conceptually, the current dissertation supports the integrative framework of body representation, in which the different representations are dynamically interacting. We propose that, in order to fully explore the mechanism of change in body representation through the implementation of physical activity intervention, the research question should be investigated in such a way that takes different representations and their mechanistic interplay into account. The present results also emphasise the differences in body representation across relevant sub-groups within the healthy populations, characterised by different levels of physical activity incorporated into their daily routine. Further research is needed to clarify the mechanism with which such differences may arise, taking into account different aspects of physical activity (e.g., exercise type and intensity, engagement characteristic), as well as whether other body-related representations not investigated here might play a role in facilitating the observed differences. Likewise, more empirical evidence is needed in order to clarify the nature of the relationship between long term sedentary behaviour and associated changes in body representation, as better knowledge with regard to these open questions could help us understand the potential role of sedentary behaviour in the development of disturbed body representation, which could further serve to perpetuate the cycle of sedentary behaviour observed to be ever increasing in today's society.

Synopsis

List of Abbreviations

3D	three-dimensional
BID	body image disturbance
BIAQ	Body Image Avoidance Questionnaire
BIQ-20	Body Image Questionnaire
BMI	body mass index (kg/m^2)
BPI	Body Perception Index
EDI-2	Eating Disorder Inventory 2
PACS	Physical Appearance Comparison Scale
PI	physical activity intervention
RHI	Rubber Hand Illusion
VAS	visual analogue scale

Theoretical Background

Body representation is relevant for the maintenance of one's sense of self, as well as for the formation of a personal identity that is both unique and invariant over time. In thinking about the body, it is important to note its dualistic nature. The body acts as the seat of cognition and sensations, from which we can observe, think about, and interact with the external world. At the same time, we are able to make observations, think about, and act upon our own bodies—much like any other objects located in the external environment. In general, dominant views in the cognitive sciences have so far been brain-centric, in that the body and its various aspects are considered peripheral to understanding the nature of the mind and cognition. For instance, Descartes' treatment of substance dualism and its application to the mind-brain relation (Descartes & Veitch, 1881) seemed to have pushed this view to an extreme. However, such views are not without opposition. Notably, the last decades have seen a distinct rise in the influence of the embodiment thesis, especially in cognitive neuroscience and related disciplines (e.g., Gallagher, 2000; 2005; Varela et al., 1991—see Barsalou, 2008 for a review). Proponents of embodied cognition stress the importance of the body in shaping cognition, in that cognition is embodied when it is causally dependent upon the attributes of the physical body (Wilson & Foglia, 2017). In other words, the embodiment thesis posits that, beyond the brain, various aspects of an agent's body play a significant role in shaping the agent's own cognitive processes. Similar to early phenomenological works by influential philosophers such as Husserl (1913; 1931) and Merleau-Ponty (1945) which argued that the very nature of human experience is underpinned by the body and its physicality, the embodiment thesis allows us to think about cognition as reliant on an accurately represented body. Therefore, it is not surprising that disturbances in body representation have been identified as a core psychopathology of various debilitating psychiatric disorders. These include disorders concerning the integrity of one's sense of self in relation to the body such as body dysmorphic disorder (Phillips et al., 2008) and body integrity identity disorder (First, 2005), as well as eating and weight disorders—especially anorexia and bulimia nervosa (Cash & Deagle, 1997; Fairburn et al., 2003; Fairburn & Harrison, 2003; Pennesi & Wade, 2016; Treasure et al., 2010).

Many different types of body representations have been identified over time; different conceptualisations arose from different literatures on the basis of different types of scientific evidence. Currently, there is no unifying theory mapping the overall relations between the different representations. The present dissertation aims to contribute to the ongoing endeavour in understanding how different aspects of body representation may interact and influence each other over time, as well as the overall mechanisms of change. In order to do so, different facets of body representation are examined in a longitudinal setting in the context of physical activity, with a focus on healthy individuals who had previously engaged in sedentary lifestyle.

Body representation: classifications and frameworks

In thinking about how the body is represented, it is useful to start with a framework which allows and accounts for the aforementioned dualistic characteristic of the body. Such a framework has been proposed and further developed by Longo and colleagues (2010; 2016), in which different types of body representations are classified into two broad categories: *somatoperception* and *somatorepresentation*. Somatoperception encompasses representations underpinning the process of perceiving the body itself—which, in addition to an egocentric frame of reference and exteroceptive perception, includes interoceptive percepts about the state of the body. Somatorepresentation, on the other hand, refers to the representations of the cognitive processes responsible for the construction of semantic knowledge and attitudes about the body. In particular, this concerns the affective-attitudinal aspect of one's cognition directed towards one's own body. As such, representations which underpin somatoperception allow for the construction of higher-level percepts concerning the body and objects in the world, while representations mediating somatorepresentation are responsible for knowledge and attitudes about one's own body as well as about bodies in general. These body representations can be further classified along two orthogonal continuums consisting of four different dimensions at each extreme, namely: perceptual—conceptual, and implicit—explicit; see Longo (2016) for this speculative model of the relations between body representations. Within this two-dimensional space, the perceptual—conceptual axis places representations under the somatoperceptual classification on the left, and somatorepresentational classification on the right. The implicit—explicit axis places representations which are accessible to conscious introspection in the upper half, and those operating as part of the cognitive unconscious in the bottom half.

Considering the placements of different body representations within this two-dimensional framework helps in thinking about a more precise nature of different representations—how they might relate to one another, how they might be measured, as well as how disruptions of particular representations could symptomatically manifest. For example, the phenomenon of a patient suffering from phantom limb syndrome, where the missing limb is perceived to be present (through sensations, painful or otherwise) even though the patient knows that it is absent (Melzack, 1992; Ramachandran & Hirstein, 1998), is remarkable. This conflict clearly demonstrates the perceptual—conceptual continuum, as the individual's disrupted perceptual representation (what the body is felt to be like; somatoperception) is incongruent with their conceptual representation (what the body is believed to be like; somatorepresentation)—the latter of which has been updated since the amputation of the limb, while the former has failed to follow suit. Thus, the phenomenon of phantom limb syndrome provides a clear example that a selective modification of representations underpinning different aspects of the body is possible—which clearly indicates that different types of body representations exist, and are subject to change.

While the current dissertation places a primary focus on the aforementioned framework by Longo and colleagues, it is important to note that multiple other taxonomies of body representation citing different criteria exist within the literature (e.g., Moseley et al., 2011; O'Shaughnessy, 1980; Felician et al., 2003; de Vignemont, 2010).

Changes in body representation: modifications, disruptions, and interventions

As we use our physical body to directly interact with the external environment, information regarding our own body, as well as the external world, are continuously processed and relevant representations updated. Findings from studies which emphasise multisensory integration imply that body representation is not fixed, but are continuously updated through the constant influx of sensorimotor information

(Dijkerman & Lenggenhager, 2018; Maravita et al., 2003). Interestingly, this plasticity can be taken advantage of and experimentally modified, thus allowing us to learn more about the different types of body representations at play. One of the most well known paradigms is the rubber hand illusion (RHI), where a prosthetic hand is placed in front of a participant, upon which tactile stimulation is visibly applied in synchrony with the participant's own hand that has been obscured. Findings from the RHI can be directly contrasted with the phantom limb syndrome, in that the illusion is able to demonstrate that an individual's subjective experience of their body can be altered, even as they know that their body's physicality has not changed (Botvinick & Cohen, 1998; de Vignemont et al., 2005). Not only did participants report that they experienced a feeling of ownership over the rubber hand, more recent studies have also shown significant changes in bodily response when the rubber hand is threatened (e.g., skin-conductance and temperature; Armel & Ramachandran, 2003; Ehrsson et al., 2008; Moseley et al., 2008), as well as a displacement effect of the location where participants felt their own obscured hand was situated (i.e., proprioceptive drift; Longo et al., 2008). Such effects of embodiment can be elicited regardless of the visual similarity shared between the participant's real hand and the rubber hand (Holmes et al., 2006; Longo et al., 2008). However, such plasticity is not without its limit. It has been demonstrated that the RHI cannot be reproduced when a non-hand object is used instead of a prosthetic hand (Tsakiris & Haggard, 2005). Similar findings from virtual reality-based body illusions have also been reported, in that embodiment effects cannot be obtained over non-body objects (Lenggenhager et al., 2007). This is interesting when taken into account with the phenomenon of the phantom limb syndrome, as this implies that mechanisms underpinning different types of body representations, while arguably plastic and updated online, cannot cope with the replacement of a body part with a non-body object—much in the same way that it cannot cope with the absence of a limb.

So far, it has been demonstrated that body representation can be experimentally modified, and from such results we are able to infer more about the nature of different types of representations underpinning our experience of the body as a whole. However, much of the literature depends on findings from clinical studies, where body representation is disrupted. Historically, it is from such evidence that the majority of the various types of body representations have been theorised and proposed. For example, the conceptualisation of the *body schema* was proposed and further developed based on patients who were able localise tactile stimulation on their body, but could not localise the placement of their limbs in external space (Head & Holmes, 1911). Additionally, the *body structural description* was proposed following investigations into the condition of autotopagnosia, in which patients retain the ability to explicitly describe the practical functions of various body parts, but are unable to explicitly locate or point to body parts belonging to themselves, nor make spatial judgments related to own body parts (Pick, 1922). The body structural description was argued to be a representation distinct from the body schema, as studies have posited it to be primarily derived from visual input, as opposed to the body schema, which were theorised to arise from multisensory integration (Buxbaum & Coslett, 2001; Sirigu et al., 1991). Neurological studies were also able to demonstrate double dissociation between body-specific topological knowledge and semantic knowledge about bodies in general (Benedet & Goodglass, 1989; Schwoebel & Coslett, 2005), which further strengthen the idea that the body structural description exists separately from the body schema.

However, of all the proposed conceptualisations of different types of body representations, *body image* is arguably one of the most widely researched representations of the past decades. Generally defined as the “subjective experience of the physical structure of our body in terms of its size, shape, and physical composition” (Longo, 2016), body image has consistently been at the focal point of interest across several fields—from psychology, psychiatry, to cognitive neuroscience. Specifically, body image disturbance (BID) has been identified as the core psychopathology in patients suffering from eating and weight disorders (Fairburn et al., 2003). Conceptually, the majority of clinical studies have proposed body image to be multifaceted, in that the representation and its related disturbances can be divided into a number of components, namely: cognitive-affective, perceptual, and behavioural (Bruch, 1962; Cash & Deagle, 1997; Legenbauer et al., 2014). The cognitive-affective component is conceptualised as the subjective evaluation of one’s own bodily appearance, while the behavioural component refers to the manifestation of body-related behaviour, specifically control and/or avoidance behaviour (e.g., comparing own body to other people’s, body-checking or fixation on specific body parts). Deficits in the perceptual component have been generally defined as an overestimation in terms of patients' perception of their own body size. However, while cognitive-affective and behavioural deficits have been evidently confirmed (e.g., Duarte et al., 2016; Legenbauer et al., 2011), recent findings were able to demonstrate that, despite the fact that inaccurate body size estimations have been frequently observed in patients suffering from eating and weight disorders (e.g., Cash & Deagle, 1997; Gardner, 2014), this is not due to a visual perceptual deficit or a lack of awareness in their body size or weight, but rather distorted attitudes with regard to their personal body-related ideals (Mölbert et al., 2017; 2018).

To date, studies reporting disruptions and experimental modifications concerning different aspects of body representation have been plentiful in comparison to experimentally designed interventions targeted at improving the adverse effects of disrupted representations. Understandably, this is in large part due to the extreme nature of most reported disruptions, which often cite neurological complications as the primary cause (e.g., brain damage or lesions). This can be seen in cases such as autotopagnosia (mislocalisation and inability to orient own body parts), somatoparaphrenia (denial of ownership of one's body parts), heterotopagnosia (mislocalisation of others' body parts associated with a intact ability in locating own body parts), body-specific aphasia (loss of body-related lexical knowledge), macro/microsomatognosia (distorted awareness of the size of the whole body or of specific body parts)—to name a few. On the other hand, causes and attributing factors to bodily disorders encountered in psychiatric contexts are intricate and often cited as biopsychosocial in nature. As such, clear mechanistic explanations remain largely a topic of debate. This applies to conditions such as body dysmorphic disorder (distorted perception of one's self-appearance), body identity integrity disorder (ownership rejection of one's own limb(s) associated with desire to have the 'alien' limb(s) amputated), and so forth. As such, few representation-targeted interventions have been put forward—with the main exception concerning body image. In the cases of eating disorders, where BID has been identified as the core psychotherapy, a number of interventions targeting body image have been developed (see Farrell et al., 2006 for a review). However, such interventions are in practice considered secondary to the standard treatment protocols, which place a higher priority to the normalisation of eating and weight-related behaviour via psychoeducation (Becker et al., 2015; Friederich et al., 2014; Legenbauer & Vocks, 2014).

In sum, there is much empirical evidence in the literature which substantiates the existence of different types of body representations—all of which provide different insights into how our bodily experience as a whole is created and maintained. While much of the theoretical underpinnings of different representations are historically built on clinical data from disorders of the bodily self, more novel experimental paradigms have been developed to extend on such findings, the most well known being the RHI. Such paradigms typically present healthy participants with ambiguous multisensory information about their body—i.e., healthy participants are confronted with body-related illusions in order to manipulate their bodily experience via experimentally 'updating' body representation (Botvinick & Cohen, 1998; Ehrsson, 2007; Ehrsson et al., 2008; Kammers et al., 2009; Lenggenhager et al., 2007). However, longitudinal investigations into how the body is represented in healthy populations are, overall, still lacking—especially those with focus on the underlying mechanism linking higher-order representations and physiology.

Body representation in healthy adults: physical activity intervention as an investigative tool

The effects of physical activity have been well documented in terms of its benefit for physical (Kwon et al., 2015; Soares-Miranda et al., 2016; Shook et al., 2015) as well as physiological (Edwards, 2006; Martinsen, 2009) health and well-being. However, the effects of physical activity on body representation is not straight forward. Physical activity has been identified as one of the main interventions implemented with the aim of improving individuals' body dissatisfaction, which is often conceptualised as negative body image (Alleva et al., 2015). While reviews of cross-sectional studies have reached similar conclusions of physical activity being an effective intervention for improving negative body image (Campbell & Hausenblas, 2009; Hausenblas & Fallon, 2006; Reel et al., 2007), studies in individuals who routinely engage in high levels of physical activity (i.e., professional athletes) show a converse effect. Highly trained athletes are reported to be at an elevated risk of suffering from both disordered eating behaviour and negative body image (Bratland-Sanda & Sundgot-Borgen, 2013; Giel et al., 2016; Sundgot-Borgen & Torstveit, 2004)—which further complicates the reported general positive association between body image and physical activity. On one hand, empirical evidence of physical activity as an effective intervention for the improvement of body image is well documented for, but on the other hand, high levels of engagement in physical activity as seen in professional athletes seem to also have a negative impact on body image. To date, there has yet to be a conclusive mechanism-based explanation for these contradictory findings. Additionally, the link between sedentary behaviour (i.e., a lack in engagement in physical activity) and body image is not well established. It is generally assumed that people who lead a sedentary lifestyle suffer from a more negative body image than those who routinely engage in some form of physical activity. However, taken together, findings so far have been few and heterogenous, and therefore inconclusive (Añez et al., 2018; Gaddad et al., 2018; Miranda et al., 2018; Shaban et al., 2016).

In essence, physical activity as an intervention is conceptually a very interesting investigative tool for examining the mechanisms of change in body representation within the healthy population. Not only can we further examine the reported fluctuations in individuals' subjective bodily appraisal in a longitudinal setting, physical activity intervention (PI) also offers the opportunity for further investigations in the interplay between different representations. In particular, the relationship between cognitive-affective body representation (i.e., body image) and physiology-related representation (i.e., interoception). A recent review by Badoud and Tsakiris (2017) proposed a possible causal link between interoceptive processing and body image concerns, whereby reduced interoceptive processing may predispose healthy individuals for a more negative body image. However, a deeper look into the literature revealed only a small number of studies examining the correlations between interoception and body image in healthy adults. Overall, a moderate inverse relationship between interoceptive accuracy and body dissatisfaction has been reported (Badoud & Tsakiris, 2017). Nevertheless, based on this line of evidence, a hypothesis of a relationship between interoception and body image in healthy individuals is plausible—especially in the context of physical activity, as engagement in physical activity encompasses increased sensory input, heightened arousal, as well as the recruitment of internal bodily processes. Additionally, interoception has been conceptualised as the representation responsible for the dynamic communications between the areas of central and the peripheral nervous systems recruited during physical activity (Craig, 2002). Previous studies have reported associations between increased interoceptive abilities and physical activity (Jones & Hollandsworth, 1981; Montgomery et al., 1984), though, when taken together, results are once again inconclusive in demonstrating a clear link between individuals' physical fitness and enhanced interoceptive abilities.

Our current project was conceptualised with limitations of the previous studies in mind. We targeted the subset of the healthy population hypothesised to be at risk for developing negative body image (i.e., sedentary adults), which have the potential to further advance into BID observed in patients with eating and weight disorders (Miranda et al., 2018). In order to overcome limitations found in cross-sectional studies, our investigation was designed to be longitudinal in order to determine patterns of different body representation-related variables over time and ensure a high level of experimental validity. In order to examine the effects of physical activity on body representation outside of the performance-driven framework, we also included a highly relevant subset of the healthy population of physically active adults who were not competing as professional athletes. As such, we aimed to fill in the research gap between the healthy and clinical populations in such way that our findings will be relevant to body representation and physical activity-related frameworks.

Aims of the present work

The present project aims to contribute to a more detailed conceptualisation of body representation and its dynamic progression through PI, as well as provides a comprehensive characterisation of different domains of body representation across subsets of the healthy population, categorised by different levels of engagement in physical activity. To this end, in cooperation with colleagues from the iReAct project and the Department of Perceiving Systems, Max Planck Institute for Intelligent Systems, we designed a well-controlled and well-structured multimethod assessment scheme which were implemented on previously sedentary healthy participants as they took part in the iReAct study, which reintroduced them to regular physical activity engagement on a weekly basis for 12 weeks.

Within the project, a series of studies were conducted in healthy individuals who routinely engage in high and low levels of physical activity, so that meaningful comparisons can be made between the sub-groups within the healthy population on the basis of physical activity. All studies utilised multimethod approach, which examined perceptual, cognitive-affective, as well as interoceptive aspects of body representation. This allowed for a more comprehensive look into the relationship between different types of body representations across both somatoperception and somatorepresentation classifications. The main foci of the sub-projects are as follows:

I. *The iReAct Project* describes the study protocol of the iReAct study—an interdisciplinary research network aimed at providing a biopsychosocial analysis of the individual response to physical activity—in which the current project is embedded.

II. *Systematic review of longitudinal PI's effects on body representation* synthesises current empirical evidence on the effectiveness of longitudinal PI on body representation. It highlights the need for future studies to consider mechanistic underpinnings of the potential bi-directional interactions between PI and body representation in order to clarify how the observed changes are brought about, as well as expand the theoretical framework to include other aspects of body representation beyond body image.

III. *Mechanism of change in sedentary adults' body image post PI* examines the relationship between interoception, affective response to physical activity, and body image outcomes in sedentary adults post 12 weeks of PI. Mediation analyses are carried out on three different hypothetical models—where outcomes from interoceptive assessments (i.e., interoceptive accuracy, interoceptive awareness, perception of interoceptive cues) are used as predictors, different aspects of affective response to physical activity (i.e., perceived activation, affective valence, exercise enjoyment, exercise avoidance) are used as mediators, and relevant sub-scales of a body image questionnaire (i.e., attitudes toward the body, perception of vitality/body dynamics) are the outcome variables.

IV. *Body representation in sedentary and physically active adults* provides a comprehensive characterisation of different aspects of body representation in sedentary adults, as well as adults who lead a continuously active lifestyle. Different components of body representation are evaluated via subjective body image-related questionnaires, empirical interoceptive tasks, computerised perceptual/depictive body adjustment task utilising biometric body models, and individualised high resolution body scans of the participants. Meaningful comparisons are made between the two groups in order to elucidate potential long term effects of physical activity on body representation.

Project overview and summary of results

All sub-projects of the current dissertation investigated body representation in healthy individuals in the context of physical activity. Variation between the sub-projects exist with regard to the exact measures implemented as well as targeted individuals. All studies utilised multimethod approach in order to facilitate and advance a broader assessment and outlook of body representation within the target population, as well as allow for interpretation of possible differences between the sub-groups.

Study I. The iReAct Project

Full title: "The iReAct study—A biopsychosocial analysis of the individual response to physical activity"

Study I details the study protocol of the iReAct study, in which the current project is embedded. The iReAct study is an interdisciplinary research network which recruited a mixed-method biopsychosocial framework in order to examine how sedentary individuals respond to two distinct standardised endurance trainings on various levels, and aimed to analyse individuals' responsiveness to physical activity in the form of a transdisciplinary approach—taking into account physiological, epigenetic, motivational, affective, as well as body image-related perspectives.

Adults who reported at least 6 months of insufficient engagement in physical activity, had body mass index (BMI) between 18.5 and 30.0 kg/m^2 and medically verified to be in good health were recruited. Participants were subsequently randomly assigned to two different training programs (High Intensity Interval Training versus Moderate Intensity Continuous Training) for 6 weeks, after which participants switched training modes in accordance with a two-period sequential-training-intervention design and trained for another 6 weeks. In order to analyse baseline characteristics as well as acute and adaptive biopsychosocial responses, three mixed-methods diagnostic blocks take place at the beginning (t_0) of the study and after the first (t_1) and the second (t_2) training period, resulting in a net follow-up time of 15 weeks. The iReAct study protocol provides details of the theoretical background, as well as the study concepts and methods of the five modules covering the aforementioned perspectives, one of which is the current project. The iReAct project's transdisciplinary mixed-method design facilitates the convergence examination of subjective and objective data, which further allows for an integrated picture of the biopsychosocial efficacy of the two distinct physical activity programs to be drawn. However, for the purposes of our current project, we are concerned with the general effects of physical activity on body representation. As such, study III examined the longitudinal effects of PI on body representation as participants progress through the iReAct training protocol and therefore utilised data from diagnostic timepoints t_0 and t_2. Study IV examined the cross-sectional differences in body representation between sedentary (iReAct participants at t_0) and physically active adults who were additionally recruited but did not take part in the iReAct training paradigm.

Study II. Systematic review of longitudinal PI's effects on body representation

Full title: "Influence of Physical Activity Interventions on Body Representation: A Systematic Review"

Study II is a systematic review of longitudinal studies which reported the effects of PI on body representation. Our review is not the first to examine the influence of PI on body representation-related outcomes across healthy and clinical populations. However, previous reviews and meta-analyses were lacking in some aspects—chief among which is the fact that previous reviews did not examine the subject matter in a mechanistic context and only focused on evaluating the effectiveness of physical activity as an intervention for the improvement of individuals' body image, broadly operationalised as body satisfaction (Alleva et al., 2015; Bassett-Gunter et al., 2017; Campbell & Hausenblas, 2009; Hausenblas & Fallon, 2006; Lewis-Smith et al., 2016; Reel et al., 2007). In other words, previous reviews were conducted from an outcome-centric perspective and did not address the fundamental research question on the potential mechanisms responsible for the reported improvement in body image after the introduction of PI. Despite the profound advancement in theoretical frameworks on body representation (e.g., de Vignemont, 2010; Longo, 2016; Longo et al., 2010), no previous reviews took into account the potential effects of PI on any other types of body representation apart from cognitive-affective body image.

In this study, we conducted a systematic review of studies reporting the longitudinal outcomes of body representation post PI implementation across healthy, sub-clinical, as well as clinical populations. All types of structured PI were included in the review. All studies were assessed individually for risk of bias via The Qualitative Assessment Tool for Quantitative Studies by the Effective Public Health Practice Project (Armijo-Olivo et al., 2012; Armstrong et al., 2008). Subsequently, a meta-analysis of studies were determined to be inappropriate due to the observed risk of bias in the majority of the studies. Reviewed studies were homogeneous in the operationalisation of body image and exclusively implemented validated body image-related questionnaires as the main outcome measure. Only three studies additionally implemented visual-oriented tasks (i.e., Stunkard Scale of Silhouette, Figure Rating Scale), which were also designed to measure the cognitive-affective aspect of body image. No study implemented body-related objective assessments (e.g., depictive or metric body size and other body-related visual estimation tasks). In sum, no other domains of body image (e.g., visual, tactile, affordance perception) or other types of body representation were investigated in the context of longitudinal PI.

Overall, we found that the implementation of structured PI is associated with improved body image. However, we argue that due to the quality of existing studies, further research is highly necessary to investigate whether the observed positive effects of PI can be generalised across populations, and, more importantly, to capture a more complete sense of body representation beyond body image in the context of PI. Due to the fact that no studies included in the review explored any form of a mechanistic interplay between PI and body representation, we could not address the main question on the potential mechanistic interplay between PI and changes in body representation as a post intervention outcome.

Study III. Mechanism of change in sedentary adults' body image post PI

Full title: "How does physical activity change body image? Exploring the roles of interoception and affective response to physical activity in longitudinal body image outcomes"

Study III applies the theoretical considerations from the systematic review (study II) and aims to broaden the theoretical and mechanistic framework underpinning PI and body representation. Broadly speaking, we wanted to address whether it was possible for an aspect of individuals' somatoperception (i.e., interoception—posited to be recruited during physical activity; Craig, 2002) to have an influence on the cognitive-affective component of somatorepresentation (i.e., cognitive-affective body image) as previously sedentary individuals start engaging in regular physical activity. Additionally, with the help of colleagues from the iReAct project (study I), we also investigated whether different aspects of individuals' affective response to being physically active could have mediating effects on the body image outcomes after 12 weeks of regular engagement in physical activity.

To this end, a multimethod approach was selected. Three different measures of interoception were implemented. *Interoceptive accuracy* and *interoceptive awareness* scores were obtained via heartbeat perception and heartbeat discrimination tasks (Garfinkel et al., 2015). Additionally, a *perception of interoceptive cues* score was obtained immediately after participants took part in the reference training session, where their subjective assessment of their experienced bodily sensations was reported on a visual analogue scale (VAS) ranging from 0 (disturbing) to 100 (beneficial). At the same time, four different self-reported measures of affective response to physical activity were also taken immediately at the completion of the reference training session. These measures were: *perceived activation*, *affective valence*, *exercise enjoyment* and *exercise aversion* (Maibach et al., 2020). These measures also used VAS to assess participants' perception of levels of arousal, feeling state, enjoyment and aversive feelings with regard to the exercise engagement they'd just completed, respectively. Body image outcomes were measured pre and post PI with the Body Image

Questionnaire's (BIQ-20; Clement & Löwe, 1996). Specifically, the BIQ-20 was selected to measure body image outcomes in the current study due to its two independent subscales: *perception of body dynamics* and *negative evaluation of the body*, which measured both perception of bodily vitality and physical efficacy, as well as subjective evaluation of participants' own appearance, respectively—the former of which is especially appropriate in the context of physical activity and interoception.

We observed an overall significant improvement in body image outcomes post PI. Interestingly, mediation analyses revealed both interoceptive accuracy and awareness measures to neither correlate with nor predicted body image outcomes. Rather, an indirect relationship between individuals' perception of interoceptive cues and participants' perception of body dynamics was observed. This is mediated by in-situ assessment of affective valence, which, in turn, has a direct effect on individuals' improvement in their perception of body dynamics post PI. In other words, individual differences in the ability to accurately perceive interoceptive signals and metaphysical awareness of such ability do not contribute to maximising improvements in individuals' body image in the context of physical activity. Rather, individuals' subjective assessment of the experienced interoceptive signals as well as their feeling states during physical activity engagement play a much larger role in contributing to a more positive long term body image outcomes.

Study IV. Body representation in sedentary and physically active adults

Full title: "Comparative differences in body representation across physically active and sedentary adults"

In Study IV, standard methods of cognitive-affective body image assessment were complemented with a novel visual body adjustment task, combined with state of the art three-dimensional (3D) body models and high resolution body scans of participants who took part. We worked closely with our collaborators at the Department of Perceiving Systems, Max Planck Institute for Intelligent Systems, to develop a computerised body adjustment task utilising biometric avatars which allowed for highly realistic adjustments to be made. From this task, combined with individualised high resolution body scan data from each participant, individuals' *body size perception* and *desired body change* were derived and quantified with Body Perception Index (BPI). These measures reflected participants' perceptual aspect of body representation (i.e., how accurately participants perceived their own body size and shape), as well as the cognitive-affective aspect of their body image (i.e., if there were demonstrable visual and empirical discrepancies between how participants perceived their current bodies and their perception of self ideal bodies), respectively. Additionally, *interoceptive accuracy*, *interoceptive awareness*, and *interoceptive sensibility* scores were obtained via heartbeat tracking and heartbeat discrimination tasks (Garfinkel et al., 2015). To further assess the cognitive-affective aspect of body image, a battery of self-report questionnaires were used: Body Image Questionnaire (BIQ-20; Clement & Löwe, 1996), selected sub-scales from Eating Disorder Inventory 2 (EDI-2; Garner et al., 1983), Body Image Avoidance Questionnaire (BIAQ; Legenbauer et al., 2007), and Physical Appearance Comparison Scale (PACS; Mölbert et al., 2017).

Here, we compared body size perception, body image, and interoception as three distinct representations under the broad definition of body representation between sedentary and physically active participants. Overall, despite both groups belonging to the healthy population, adults who have been sedentary for at least 6 months generally represent their body differently from their physically active counterparts. Active participants represent their bodies with more positive levels of body image, as seen from both experimental visualisation and questionnaire-based findings. Participants in the active group also performed significantly better in interoceptive tasks and reported higher levels of confidence in their interoceptive abilities.

Discussion

Taken together, the current dissertation not only provided clear evidence of the effects of long term physical activity engagement in body image, it also made the first much needed attempt to propose and examine the mechanistic interplay between body representation and physical activity in a longitudinal context. More importantly, the project also yielded first results concerning other types of body representation (i.e., interoception and perceptual body size/shape representation) beyond cognitive-affective body image in terms of how they are influenced by routine engagement in physical activity. With the advantage of methodological advancements and the development of novel experimental tasks, our project offered new results and insights into how body representation as a whole is characterised across different groups (i.e., sedentary versus physically active) within the healthy population, which is highly relevant for basic research, in addition to its implications in practical health-related outcomes.

Synthesis and interpretation of results

The general findings outlined in the systematic review (study II) showed that, while there has been an abundance of studies evaluating the effectiveness of physical activity as an intervention to improve individuals' body image (specifically, body satisfaction), there is no real theoretical explanation as to why this should be the case. While the term body image has been characterised as the conscious, predominantly visual, mental representation of one's own body (Longo, 2016), previous studies have shown that no objective improvement in bodily shape, composition or physical fitness is needed in order to achieve improvements in body image (Campbell & Hausenblas, 2009). As such, the mechanism driving this observed improvement cannot be the diminishing of the so-called gap between individuals' perception of their own current bodies and their ideal bodies. This is surprising, insofar as people typically assume that their body image is based on an objective evaluation and visual comparison of their bodies to a certain ideal that they aspire to. Instead, findings from study III suggest that complex appraisal processes brought about by more intense and frequent somatosensation experiences during physical activity play a more important role. This is in line with previous studies, where PI were theorised to improve body image by allowing individuals to redirect their attention more toward the functionality of their bodies and less on their appearance (Ginis & Bassett, 2011; Martin & Lichtenberger, 2002). In other words, when it comes to maximising long term body image improvement, objective markers of physical fitness matter less than individuals' own sense of physical efficacy and their in-situ affective response to being engaged in physical activity.

However, the line of evidence generated by the current dissertation does not adequately explain the contradictory findings found in professional athletes, where negative body image and disordered eating behaviour have been reported (Bratland-Sanda & Sundgot-Borgen, 2013; Giel et al., 2016; Sundgot-Borgen & Torstveit, 2004). Nevertheless, findings from study IV, where the target population included physically active adults who were not professional athletes, allowed us to take the first step towards filling in the theoretical and empirical gaps in the literature. Despite the fact that the cross-sectional nature of the study does not allow causal inference to be determined, there is compelling evidence that although impaired body image and disordered eating frequently occurs in professional athletes, this is unlikely due to the duration, intensity, or frequency of being physically active alone. Rather, the likely causes were proposed to be the sociocultural and sport-specific pressures exerted on and internalised by the athletes and their immediate social and professional environments (Giel et al., 2016; Lunde & Gattario, 2017; Petrie & Greenleaf, 2012; Reel et al., 2013). As such, theoretically, individuals who are not under pressure achieve certain body shapes or compositions in order to excel at certain sports are likely to be more free to simply enjoy their engagement in whichever physical activity or sport they may choose and therefore benefit more, body image-wise and further, from being physically active.

Implications for basic research and health-related interventions

In this dissertation, a wealth of empirical evidence across a number of literatures have been presented to substantiate the existence of a variety of body representations underpinning our day-to-day bodily experience. It has been shown that, while these representations are susceptible to clinical impairments and experimental modifications, less is known about how they might interact with each other when a healthy individual engages in a long term intervention—in this case, physical activity. The aim of the dissertation was not only to investigate the mechanisms underpinning the reported interactions between physical activity and body image, but also to propose and examine a larger, more comprehensive framework, in which other body-related representations are taken into account.

Considering the embodiment thesis, as well as previous studies emphasising the role of multisensory integration in the relationship between the body and cognition (e.g., Dijkerman & Lenggenhager, 2018), it was imperative for our current project to take into account representations under the classification of somatoperception as well as somatorepresentation (Longo et al. 2010; Longo, 2016). As such, study III was designed with the aim to elucidate the longitudinal relationship between interoception and body image in the context of physical activity. Previous literature on the correlations between interoception and body image in healthy populations are few, cross-sectional in design, and reported a moderate inverse relationship between interoceptive accuracy and body dissatisfaction (Duschek et al., 2015; Emanuelsen et al., 2015; Holmes et al., 2015). However, our findings from study III were the first to clarify that, while there is indeed a link between how the body is physiologically experienced and subsequently cognitively evaluated (as demonstrated by observed embodiment effects in RHI and VR studies, for example), the relationship is more complex with regard to a long term intervention. While a cross-sectional examination in study IV also showed a more positive body image and higher interoceptive accuracy in physically active participants as compared to those who were sedentary; study III demonstrated that individual differences in interoceptive abilities did not matter for the long term improvement of body image as long as the experienced physiological signals from being physically active were perceived to be beneficial and associated with positive affect. This is interesting, especially when taken together with studies where fitness level improvement and body composition were not found to moderate the effect size of PI on body image outcomes (Campbell & Hausenblas, 2009)—as this further emphasises the importance of the individual's subjective evaluation of their physiological signals, as well as their emotional affect arising from engaging in physical activity.

Although our project did not directly address the clinical population, the overall findings may be useful for the future development of therapeutic interventions targeting clinical or sub-clinical groups suffering from disturbed body image. In that, if PI were deemed appropriate to be implemented for the goal of improving body image and utilised as a preventative measure against the development of BID, special emphasis should be placed on the individuals' interoceptive evaluation and affective response while being engaged in physical exercise, as opposed to focusing on achieving a certain marker of physical fitness. Populations generally deemed at risk of developing BID include individuals suffering from obesity, as well as those who engage in long term sedentary behaviour. However, despite the fact that BID has been classified as a core psychopathology in eating disorders, strong caution must be taken when considering physical activity as a possible intervention—as a substantial number of patients with eating disorders reported symptoms of excessive exercise and motor restlessness. More specifically, excessive exercise associated with negative affect (e.g., feelings of intense guilt and fear of weight gain following exercise avoidance) has been reportedly observed in approximately 40–80% of patients with anorexia nervosa (Davis et al., 1997). As such, PI is not considered an established treatment for patients suffering from eating disorders. However, though controversial, some researchers consider PI to have a part in the development of comprehensive treatments promoting weight restoration, which include a gradual reintroduction and normalisation of healthy amounts of physical activity through structured and closely monitored PI, which may help attenuate treatment-related distress and bring about beneficial changes in body image, while controlling pathological exercise motivation (Hausenblas et al., 2008; Zunker et al., 2011). More importantly, from our current findings, therapeutic methods designed with the goal of inducing positive affect associated with physical activity may have great benefits toward this normalisation of patients' relationship with exercise, as well as help elevate BID-related symptoms. Regardless, much more research is needed before any kind of PI is introduced to clinical populations who are especially vulnerable to physical activity related symptoms.

Methodological considerations

The strength of the current project lies in the theoretical considerations which directly informs the study design. Novel findings and insights were gained by adopting a longitudinal multimethod approach, which facilitates a more comprehensive and up to date framework of body representation to be brought into the context of physical activity research. This results in a more complex and comprehensive model of the interplay between different types of body representations in healthy individuals as they undergo PI—which has further potential to inform future studies. Additionally, we did not only investigate such mechanisms in the general healthy population, but seek to target relevant sub-groups based on their levels of engagement in physical activity. This is of special relevance, as findings on body representation and related disruptions exist in athletes and individuals suffering from eating and weight disorders, but not those who are simply physically active or sedentary—the latter of which is highly relevant, as sedentariness has been implicated as a precursor to healthy individuals suffering from negative body image, which has the potential to increase in severity and develop into BID (Miranda et al., 2018)

With the advantage of innovative methodological advances and state of the art body scan technology, data obtained in this project were more informative as compared to previous studies examining similar topics of investigation. In particular, the development and implementation of highly realistic biometric body models in study IV represent a substantial methodological improvement as compared to previous research, which relied almost exclusively on self-reported questionnaires. For the first time, we were able to compare participants' veridical bodies (obtained from the body scan) to body models generated by the participant themselves via the computerised experimental task. Not only were we able to visually examine and empirically quantify whether participants accurately represent their body size and shape, participants' degree of body satisfaction could also be examined in the same way via the calculations of BPI.

In sum, the biometric body adjustment task has been demonstrated to be impressively valid. Data obtained were plausible, and participants were demonstrably very proficient at using the body models to recreate their self avatar and reported the task to be extremely easy to use. However, BMI estimation from the body models created from the task could be problematic when implemented in populations whose body compositions lie outside the norm (e.g., very lean, severely underweight, or obese individuals), as the calculated estimation of BMI from skinned multi-person linear models (SMPL; Loper et al., 2015) relies on the average human body density (1010 kg/ m^3; Satoh, 1992). This potential distortion in BMI estimation would subsequently be reflected in the BPI measure. Nevertheless, we believe that the introduction of this methodological approach involving naturalistic human bodies would open up new and more innovative venues to assess body-related perceptions and ideals in both healthy and clinical populations.

The present project also has several limitations, chief among which is the relatively small sample size due to the pilot character of the studies. Additionally, all participants volunteered to take part, which does not allow findings to be readily applicable to the average population, especially those with no inherent drive to complete interventions involving physical activity. Although study III incorporated a longitudinal design, implementing follow-up assessments at later time points would also be highly beneficial. Not only would it clarify whether PI could produce a lasting improvement in body image outcomes past 12 weeks, the verification of the mediation effects between interoception, affective response, and body image outcomes at later follow-up assessments would also be extremely relevant the construction of a more detailed picture of this dynamic interplay between different body representations.

Conclusions and further directions

Overall, the present project contributes to a more thorough conceptualisation of body representation and its dynamic progression through PI. Our findings also contribute to a more comprehensive characterisation body representation across subsets of the healthy population, categorised by different levels of engagement in physical activity. In particular, sedentary adults have been demonstrated to represent their bodies differently across a number of representations as compared to physically active adults. Therefore, further research with a larger sample size is needed to clarify the mechanism with which such differences may arise. Additionally, more empirical evidence is needed in order to clarify the nature of the relationship between long term sedentary behaviour and associated changes in body representation.

Deeper knowledge with regard to these open questions could help us understand the potential role played by sedentary behaviour in the development of disturbed body representation—which could, in turn, contribute to the formation and maintenance of the experience of cognitive barrier to exercise, and thus further perpetuating the cycle of sedentary behaviour. This is especially relevant, as recent trends in adult sedentary behaviour show no sign of decreasing, unlike trends in exercise-related behaviour which continue to stagnate (Du et al., 2019). In an attempt to further combat this increasing trend in sedentary behaviour, future developments of interventions aimed at improving individuals' affective response to physical activity, as well as guidelines to help bring about more positive assessments of their own interoceptive signals experienced during physical activity, are highly recommended. Specifically, for the purposes of increasing long term exercise adherence, as well as maximising improvement in body image (and perhaps, with future findings, other body-related representations) across the adult populations.

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Statement of Contributions

Study I. The iReAct Project

Thiel, A., Sudeck, G., Gropper, H., Maturana, F. M., Schubert, T., Srismith, D., Widmann, M., Behrens, S., Martus, P., Munz, B., Giel, K., Zipfel, S., & Nieß, A. M. (2019). The iReAct study – A biopsychosocial analysis of the individual response to physical activity. *Contemporary Clinical Trials Communications*, *17*. https://doi.org/10.1016/j.conctc.2019.100508

The study protocol was conceptualised by Ansgar Thiel, Gorden Sudeck, Barbara Munz, Katrin Giel, Stephan Zipfel, Simone Behrens and Andreas Nieß. Ansgar Thiel, Gorden Sudeck, Andreas Nieß and Hannes Gropper prepared the manuscript drafts. Hannes Gropper, Felipe Maturana, Tanja Schubert, **Duangkamol Srismith** and Manuel Widmann contributed to the refinement and implementation of the study protocol. Peter Martus provided statistical advisory support and the generation of the allocation sequence. All authors critically reviewed the drafts and approved the final manuscript before submission.

Study II. Systematic review of longitudinal PI's effects on body representation

Srismith, D., Wider, L.-M., Wong, H. Y., Zipfel, S., Thiel, A., Giel, K. E., & Behrens, S. C. (2020). Influence of Physical Activity Interventions on Body Representation: A Systematic Review. *Frontiers in Psychiatry*, *11*, 99. https://doi.org/10.3389/fpsyt.2020.00099

The study was conceptualised by **Duangkamol Srismith**, Katrin Giel and Simone Behrens, with contributions from Stephan Zipfel and Ansgar Thiel. **Duangkamol Srismith** performed the literature search, screening and rating of the results, as well as data collection. Leona-Magdelena Wider was the second screener for titles of the identified records. Simone Behrens screened the abstracts of the identified records and performed ratings for the included studies. Hong Yu Wong contributed to the theoretical background and updated framework for body representation. **Duangkamol Srismith** drafted the manuscript and generated the figures and tables. All authors critically reviewed the drafts and approved the final manuscript before submission. **Duangkamol Srismith** implemented the revision drafts and was in charge of the correspondence during the peer-reviewing process.

Study III. Mechanism of change in sedentary adults' body image post PI

Srismith, D., Dierkes, K., Zipfel, S., Thiel, A., Sudeck, G., Giel, K. E., & Behrens, S. C. How does physical activity change body image? Exploring the roles of interoception and affective response to physical activity in longitudinal body image outcomes. *Under review at Journal of Sport and Exercise Psychology.*

This study was conducted as a sub-project of the iReAct study (study I), which was conceptualised by Ansgar Thiel, Gorden Sudeck, Barbara Munz, Katrin Giel, Stephan Zipfel, Simone Behrens and Andreas Nieß. Ansgar Thiel was the principal investigator and managed the main project. **Duangkamol Srismith** and Katja Dierkes conducted the research and investigation process, specifically performing experiments and data collection. **Duangkamol Srismith**, Katrin Giel and Simone Behrens designed and developed the methodology. **Duangkamol Srismith** was in charge of the preparation, creation and presentation of the published work, specifically the data analysis and writing of the initial draft. **Duangkamol Srismith**, Katrin Giel, Simone Behrens, Ansgar Thiel, Gorden Sudeck and Katja Dierkes contributed to the interpretation of results. All authors critically reviewed the drafts and approved the final manuscript before submission. **Duangkamol Srismith** implemented the draft revisions and the correspondence during the peer-reviewing process.

Study IV. Body representation in sedentary and physically active adults

Srismith, D., Quiros-Ramirez, M. A., Reh, A., Black, M. J., Zipfel, S., Thiel, A., Giel, K. E., & Behrens, S. C. Comparative differences in body representation across physically active and sedentary adults. *Under review at Behavior Research Methods.*

Statement of Contributions

This project was conducted as a collaborative project between the iReAct project and the Department of Perceiving Systems of the Max Planck Institute for Intelligent Systems. Additionally, it was a sub-project of the iReAct study (study I), which was conceptualised by Ansgar Thiel, Gorden Sudeck, Barbara Munz, Katrin Giel, Stephan Zipfel, Simone Behrens and Andreas Nieß. Ansgar Thiel was the principal investigator and managed the main project. **Duangkamol Srismith,** Katrin Giel and Simone Behrens designed and developed the methodology. **Duangkamol Srismith** and Anne-Christine Reh conducted the research and investigation process, specifically performing experiments and data collection. **Duangkamol Srismith** and Simone Behrens were in charge of the management and organisation of the contributions from different departments. **Duangkamol Srismith** set up the pipeline codes and carried out the alignment for the body scans. Maria Alejandra Quiros-Ramirez generated the body models and differential figures. **Duangkamol Srismith** was responsible for the preparation, creation and presentation of the published work, specifically the statistical data analysis and writing of the initial draft. **Duangkamol Srismith**, Katrin Giel and Simone Behrens contributed to the interpretation of results. All authors critically reviewed the drafts and approved the final manuscript before submission. **Duangkamol Srismith** and Simone Behrens implemented the draft revisions. **Duangkamol Srismith** was in charge of the correspondence during the peer-reviewing process.

Manuscripts

Contemporary Clinical Trials Communications 17 (2020) 100508

Contents lists available at ScienceDirect

Contemporary Clinical Trials Communications

journal homepage: http://www.elsevier.com/locate/conctc

Research paper

The iReAct study – A biopsychosocial analysis of the individual response to physical activity

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ARTICLE INFO

Keywords:
Physical activity
Response
Biopsychosocial
Transdisciplinary
Individualised training
Mixed-methods

ABSTRACT

Background: Physical activity is a substantial promoter for health and well-being. Yet, while an increasing number of studies shows that the responsiveness to physical activity is highly individual, most studies focus this issue from only one perspective and neglect other contributing aspects. In reference to a biopsychosocial framework, the goal of our study is to examine how physically inactive individuals respond to two distinct standardized endurance trainings on various levels. Based on an assessment of activity- and health-related biographical experiences across the life course, our mixed-method study analyzes the responsiveness to physical activity in the form of a transdisciplinary approach, considering physiological, epigenetic, motivational, affective, and body image-related aspects.

Methods: Participants are randomly assigned to two different training programs (High Intensity Interval Training vs. Moderate Intensity Continuous Training) for six weeks. After this first training period, participants switch training modes according to a two-period sequential-training-intervention (STI) design and train for another six weeks. In order to analyse baseline characteristics as well as acute and adaptive biopsychosocial responses, three extensive mixed-methods diagnostic blocks take place at the beginning (t_0) of the study and after the first (t_1) and the second (t_2) training period resulting in a net follow-up time of 15 weeks. The study is divided into five modules in order to cover a wide array of perspectives.

Discussion: The study's transdisciplinary mixed-method design allows to interlace a multitude of subjective and objective data and therefore to draw an integrated picture of the biopsychosocial efficacy of two distinct physical activity programs. The results of our study can be expected to contribute to the development and design of individualised training programs for the promotion of physical activity.

Trial registration: The study was retrospectively registered in the German Clinical Trials Register on 12 June 2019 (DRKS00017446).

1. Introduction

Physical activity is considered one of the most relevant strategies for the promotion of biopsychosocial health. Regular physical activity not only lowers the risk of cardiovascular diseases [1], type 2 diabetes [2,3], and cancer [4,5] and prolongs life expectancy [3] but also has positive effects on mental well-being and fosters the development of personal resources, the sense of achievement, and social networks [6,7].

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https://doi.org/10.1016/j.conctc.2019.100508
Received 11 September 2019; Received in revised form 3 December 2019; Accepted 12 December 2019
Available online 17 December 2019

Consequently, the World Health Organization (WHO) recommends that "adults aged 18–64 years should do at least 150 min of moderate-intensity aerobic physical activity throughout the week, or do at least 75 min of vigorous-intensity aerobic physical activity throughout the week, or an equivalent combination of moderate- and vigorous-intensity activity" [8].

In recent years, there has been an increasing number of studies that show that people respond individually and in different ways to exercise, both physiologically and affectively. These results imply that stereotypical advice for health-promoting physical activity is inadequate. However, both a comprehensive framework for the investigation of individual effects of physical activity and empirical evidence supporting differential counselling are still missing.

The study presented here is designed as an interdisciplinary research network consisting of five modules. Based on an analysis of activity- and health-related biographies, we investigate individual physiological, affective, and cognitive responses to high-intensity interval training (HIIT) versus moderate intensity continuous training (MICT). In contrast to most of the foregoing studies, which have primarily been monodisciplinary approaches (e.g. physiological, biomedical, or psychological) we aim to adopt, in a proof-of-principle approach, a holistic biopsychosocial perspective in order to account for individuality.

2. Theoretical framework

2.1. A transdisciplinary model of biopsychosocial response to physical activity

A fundamental assumption of our project is that the individual responsiveness to physical activity cannot be explained by monodisciplinary paradigms only. Individual development over the lifecourse [9] is a result of an interaction of psychosocial, affective, and physiological factors that leads to the formation of distinctive patterns. Individual responsiveness to physical activity and its consequences for the human being therefore has to be analysed as a complex biopsychosocial entity.

Early biopsychosocial models have been criticized due to their lack of differentiation. In order to explain individual differences in physical activity behaviour and response, more differentiated transdisciplinary models are needed. A model by Bryan et al. [10] integrates different disciplinary approaches (incorporating molecular approaches, animal models, human laboratory models, and social psychological models), and therefore claims to enable "a better understanding of characteristics of individuals that are important in the adoption and maintenance of physical activity" [10 p20]. According to Bryan's model, the acute physiological response depends not only on the actual exercise behaviour, but also on genetic factors, the subjective experience of exercise (such as the perceived exertion, changes in affect, changes in arousal, and pain), and the motivation to exercise (including the attitude towards/self-efficacy for exercise, the intentions to exercise, the intrinsic/extrinsic motivation, expectancies, goals, and the self-concept). However, Bryan's model does not cover all factors that are relevant for the explanation of biopsychosocial responsiveness to physical activity. In our perspective, the subjective responsiveness is influenced by the individual's biography (as the subjective core element of individuality) and by the image the individual has of his/her own body. As we will explain in the following, these influences are not limited to an affective dimension, but also have physiological effects.

In order to depict developmental processes of individuality, we developed a transdisciplinary process model that is built on the framework by Bryan et al. [10]. In our model, the biography bundles all subjective experiences with regard to physical activity and health. The actual subjective responsiveness to a physical activity stimulus is reflected in affective and motivational responses and the body image. Epigenetic factors and the physical condition have an impact on the physical response to exercise, while the subjective experiences of physical activity are psychologically processed and in consequence influence body image and motivation. Adaption in the medium and long term depends on the repetition of training bouts and their biological, psychological and social processing. In turn, the changed state of epigenetic factors, physical condition, body image and motivation to exercise determines the future reconstruction of past experiences (the "future biography") and therefore future physical activity behaviour (Fig. 1).

2.2. The individual biography as a core factor of the individual response to physical activity

In orientation to studies on the (un)willingness of people to be physically active, we assume that the individual responsiveness to physical activity is not solely genetically predetermined and unchanging, but develops and changes over the life course. According to these studies, factors such as gender, social networks, environmental influences, or social and cultural norms are key correlates of physical activity, besides genetic, evolutionary physiological, political and global factors [11,12]. Although the findings of these studies give reason to assume that context-related factors, such as neighbourhood, social support, or education, influence activity behaviour and its effects, the mechanisms of the individual response to physical activity still remain unclear.

In our opinion, a key mechanism lies in the way how individuals reconstruct past experiences in physical activity-related contexts. On the one hand, the way a person reconstructs his/her past experiences is decisive for his/her subjective individuality (or, in other words, the feeling of being different from others). What makes a person unique as an individual is encapsulated in the experiences that he/she has made over the life course. On the other hand, memory research shows that the meaning that individuals attach to past events are ever changing depending on their present circumstances [13]. This leads to the assumption that the *currently remembered* history is more predictive regarding future behaviour than what *actually happened* in the past. This holds particularly true as the individual biography contains reflections about the individual's capacity to overcome "disruptive experiences" [14,15] such as illness, personal crises, stigmatisation, or discrimination experiences [16]. From this perspective, biographies have to be considered a core factor of the subjective individual response to physical activity.

Biographies are mental constructs that become available through narration. Processes of reflection allow access to past experiences and eventually shape biographies in the form of a 'reflexive self-consciousness', including concepts of past, present, and anticipated future [17]. Hence, the analysis of individual biographies reveals information on how and why a person acts in activity- and health-related settings. However, the role biographies play with regard to the individual response to physical activity has barely been studied by now.

2.3. Body image and responsiveness to physical activity

Biographies also determine how we see ourselves in general and our body in particular. Body representation is a multifaceted construct encompassing a conglomerate of perceptual versus conceptual representations which can be more or less explicit [18,19]. The image an individual has of his/her own body is an integration of physiological sensations from the body with cognitive, emotional, and motivational perceptions and self-reflections of one's own body and physical health. These self-reflections root in the past and are therefore an integral part of the individual's life story.

Many studies report that physically active persons tend to be more satisfied with their body and also more sensitive towards physiological signals from the body [e.g. Ref. [20]]. Additionally, reduced abilities to form conscious representation of internal physiological signals have been theorized to predispose healthy individuals for greater body image

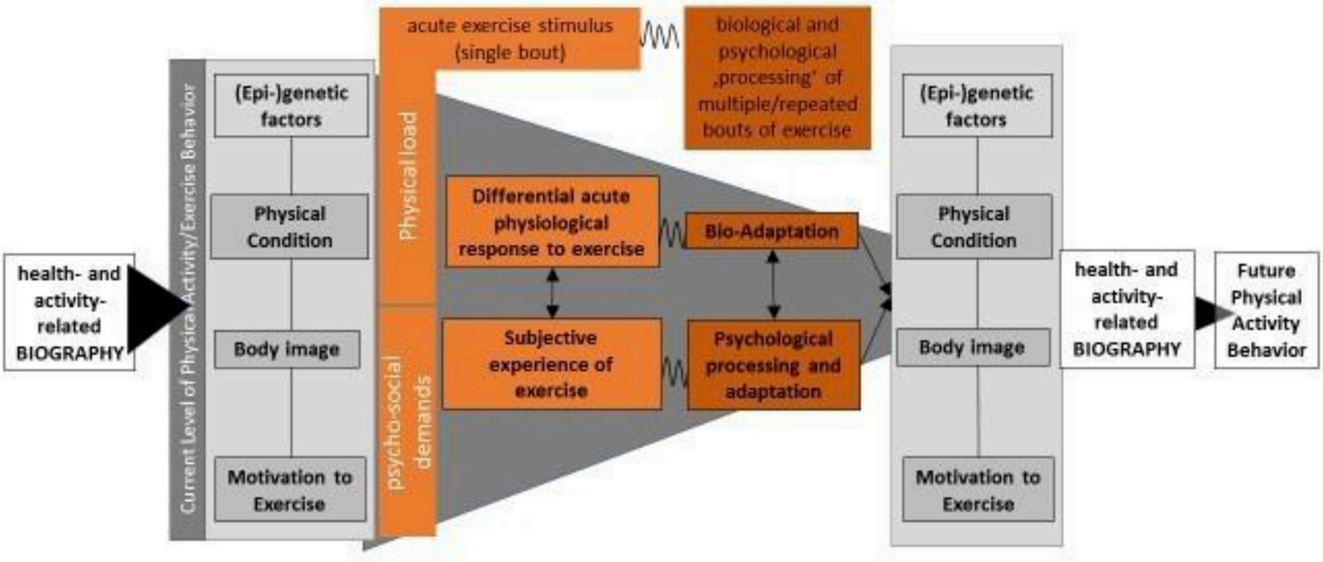

Fig. 1. Transdisciplinary model of responsiveness to physical activity.

dissatisfaction, as well as the development of eating disorders or the severity of body image disturbances in clinical populations [21]. On the other side, internalization of weight-related criticism, for example, goes along with a significantly reduced willingness to be physically active [22]. Obese people tend to avoid diets and regular physical activity if they integrate discrimination experiences into their self-concept [23–25]. It is assumed that the relationship between body representation and physical activity is bi-directional: One's own body image (e.g. body dissatisfaction) might present a motive for engaging in physical activity [26] and physical activity in turn, might influence body representation. By now, however, there is almost no systematic research on the individual response to different forms of physical activity with respect to the individual body representation.

2.4. *The affective responsiveness to physical activity*

Over the last years, exercise psychology has put an increasing emphasis on inter-individual differences in the affective response to physical activity [27,28]. Recent studies document a substantial inter-individual variability in affective responses to exercise dependent on the intensity of physical activity [29,30]. At vigorous intensity levels there seems to be a particularly high inter-individual variability. In very high exercise intensities, interoceptive cues (e. g. heavy breathing or muscular pain) are supposed to overrule cognitive processes and strengthen the link between interceptive factors and the affective response to activity [31]. However, it is still unclear to which extent the physiological response correlates with the affective response to physical activity.

Furthermore, research on the affective response to physical activity depending on different training regimens, such as HIIT versus MICT, has revealed somewhat contradictory results. While Martinez et al. [32], Kilpatrick et al. [33] and Little et al. [34] conclude that heavy interval training is more enjoyable for the participants than heavy continuous training, other studies report HIIT regimes as inappropriate for a largely sedentary population, particularly because of the lack of enjoyment [35]. The controversial discussion is very well documented in an article by Biddle & Batterham [36]. While Biddle argues that high-intensity exercise has a psychologically aversive nature which, in turn „will predict drop out or a marked reduction in exercise intensity over time during self-regulated exercise bouts", Batterham refers to a compelling number of articles that are „reporting comparable exercise enjoyment and confidence to engage in a HIIT protocol" [36 p2]. However, due to limited and inconclusive research, reliable conclusions for the individual affective and motivational processing of the different exercise regimes are not possible.

2.5. *The variety of physiological responses to physical activity*

It is well documented that the physiological effects of physical activity are dependent on the intensity and the type of exercise [37]. However, most physiological and health-related outcomes of physical activity vary highly from person to person [38,39]. A genetic explanation for this variation is the association between single nucleotide polymorphisms (SNPs) and the extent of phenotypic adaptation. For example, SNPs of the Brain-Derived Neurotrophic Factor (BDNF) or of the nuclear hormone receptor peroxisome proliferator-activated receptor δ (PPARδ) and its transcriptional coactivator PPARγ coactivator 1α (PGC-1α) have been shown to be related to physiological and affective responses to exercise [40,41]. Other researchers state that the beneficial effects of physical activity on cardiometabolic risk factors, the risk of cardiovascular disease and cancer, are modulated by a number of co-variables, such as pre-existent fitness, gender, anthropometry, life time exposure to physical activity, and others [42–47]. Moreover, it has been shown recently that the failure of adapting insulin sensitivity to exercise training is associated with impaired upregulation of mitochondrial fuel oxidation genes and an augmented pro-inflammatory state in skeletal muscle [47]. Finally, recent data indicates that the adaptive response to exercise, particularly skeletal muscle adaptation, is controlled by epigenetic mechanisms, such as differential DNA methylation, histone modification, and microRNA (miRNA) expression [for review see Refs. [48,49]].

Apart from this, there is an ongoing discussion about the percentage of non-responders to physical activity with respect to risk factor reduction. In some studies, this percentage is estimated at up to 20% of all exercisers [46,50]. In contrast, however, a recent study [51] concludes that non-responding to physical activity in terms of a blunted increase of maximum oxygen consumption (VO_{2max}) is a myth – i.e. that everybody can physiologically benefit from regular physical activity – and that the only relevant factors are the type and the dose of activity, which have to be individually tailored. Moreover, an immediate change in the type of training, e.g. from MICT to HIIT may allow supposed non-responders to MICT to adapt successfully to HIIT.

In this context, more recent research suggests that more vigorous exercise such as HIIT may be superior to continuous exercise performed with low or moderate exercise intensities. Thus, most studies could prove an advantage of the HIIT with the improvement of VO_{2max} [52]. With regard to more clinical endpoints, such as insulin sensitivity, blood pressure or BMI, the advantage of HIIT over low or moderate was less uniform [53–56].

2.6. Research desiderates

Existing research suggests that people should get individually tailored advice on how to be physically active. What has not been thoroughly analysed by now is how the subjectively experienced individuality of a person (represented in his/her biography, the body image, and the motivation to exercise) and the individual physiological stress response to a standardised bout of exercise (training session) influence the adaptive response to exercise regimes. How physiological and affective responses to physical activity correlate has also been hardly investigated.

3. Study concept and methods

3.1. Central research questions

It can be summarized that the individual responsiveness to physical activity has only been partly studied by now. Furthermore, the existing findings are to a certain extent ambiguous. Against the background of this research desideratum, our project focuses on the following questions:

How do individuals physiologically, epigenetically, cognitively and affectively respond to two sequential intervention training programs with significantly different intensities but the same energy consumption? To which extent do the type and the sequence of the interventions influence the final outcome?

Specific sub-questions will be addressed in five study modules, which have their own central research questions (see below). Beyond these individual questions, the joint project aims to analyse overarching research questions regarding the biopsychosocial response to physical activity, such as for example:

a. To which extent do physiological, epigenetic, and affective responses correlate?
b. What role does the individual stress response to a standardised bout of exercise play with regard to the individual physiological, epigenetic, and affective responsiveness to physical activity?
c. What role does the health- and activity related biography play with regard to the individual physiological and affective responsiveness to physical activity?
d. Are there typical activity- and health-related biographies and do they correlate with physiological and affective responses to physical activity and the individual body image?
e. How does the reconstruction of training experiences during the intervention relate to the in-situ affective and physiological outcomes?
f. What role does the individual body representation (the satisfaction with the own attractiveness, interoceptive abilities, the perception of the own physical capacity or the degree of body acceptance in general) play with regard to the individual physiological and affective responsiveness to physical activity? Does the individual body image change dependent on different forms of physical activity?
g. Do the data allow to categorise the subjects regarding responsiveness-related characteristics? Can high- and low-response groups be identified?
h. Are specific epigenetic markers predictive for a “high” or “low” affective and/or physiological response to a particular type of training?
i. How are biological adaptions, changes in motivation and body image related? To which extent are these relations modulated by type and sequence of exercise regimes or factors such as gender, and social networks?

Due to these joint research questions, our study is characterised by an integral approach. This means on the one hand that all participants will have to participate in all experiments/tests/interviews. On the other hand, the collected data will be stored in a joint database.

Not least, the project aims at identifying translational strategies that can be transferred to specific target groups. In this regard, the following questions will be relevant:

- What are the main specifics that have to be considered for the individualised development of training programmes, when a transdisciplinary approach is applied?
- How can personalised training recommendations be integrated into the subjects’ life-worlds?

3.2. Sample and subject recruitment

Thirty men and thirty women, aged 20–40 yrs, will be recruited for the study. Further inclusion criteria are:

- Non-smokers
- BMI between 18,5 and 30,0 kg/m^2
- Currently not meeting WHO-recommendations for moderate physical activity (less than 150 min/week)
- Less than 60 min/week of exercise during leisure time (including sports participation, endurance-oriented activities, muscle strengthening) and no regular exercise for several weeks during the last six months
- Maximum oxygen uptake (VO_2max) between 25 and 50 ml/min/kg
- No current or former eating disorder or obesity
- No severe internistic or neurological previous illness
- No pregnancy or breastfeeding period
- German as a native language

Reasons for exclusion are:

- Chronic diseases or findings that results in a decreased ability to participate in a physical activity intervention
- Medication or supplement intake within the last 4 weeks, which according to the physicians might interfere with the study results (exception: contraceptives)
- Counter indication(s) for local anesthetics
- Clinically relevant deviations in the lab results
- Pathological indications in the resting-ECG
- Vein conditions that do not allow for multiple blood sampling
- Participation in a medication study within the last three months
- Drug use, alcohol abuse
- Current psychotherapy

Participants are primarily recruited via the university mailing list and the university clinics mailing list. Additionally, postings on the MPI Experimental Database, advertisements, newspaper articles, and online presence on the homepage of the institute of sports science are employed to raise awareness for the study. Interested parties are provided with detailed information on the study protocol and are asked to fill in a physical activity questionnaire (European Health Interview Survey – Physical Activity Questionnaire (EHIS-PAQ)) in order to assess current physical activity levels. Furthermore, an additional telephone screening to check eligibility criteria is done. Finally, a medical examination takes place prior to final enrolment in the study. As a part of this examination, interested parties are once again informed about the study protocol and requirements, and a written informed consent is obtained.

Data collection takes place at the institute of sports science, the department of sports medicine and the Max Planck Institute Tübingen.

The participants are enrolled at the Department of Sports Medicine of the University Clinic Tübingen by physicians and trained personnel. The data is entered by the members of the research team. All collected data is anonymized and stored on a safe database at the University of Tübingen, which can only be accessed by members of the research team.

3.3. Two-period sequential-training-intervention (SIT)

Women and men will be randomly assigned to two training groups. As exercise intensity is a potential factor, which influences the individual response to training, we will compare two different concepts of endurance training using a sequential training intervention design. This means that the participants start with MICT respectively HIIT and then switch to HIIT respectively MICT without a wash-out period between the two interventions. Each training period will last 6 weeks and consists of three weekly training sessions. This procedure allows us to compare the outcomes of HIIT vs. MICT after the first follow-up analysis and the influence of the sequence of both interventions on the final outcome after the second follow-up.

Training of group MICT will consist of **M**oderate **I**ntensity **C**ontinuous **T**raining, while HIIT will be realised via a **H**igh-**I**ntensity-**I**nterval-**T**raining. Energy consumption will be adjusted to be nearly identical in both trainings sessions and is planned to be approximately 8 MET-hrs. per session.

Group MICT will perform continuous cycling exercise at a power output (PO) corresponding to 90% of the first lactate threshold (LT) for 60 min three times a week [57–59]. The HIIT group will perform a 10-min warm-up at a PO corresponding to 70% of maximal heart rate (HR_{max}), followed by 4 x 4-min intervals at a PO corresponding to 90% HR_{max} with a 4-min active resting period at 30 W between each interval (such exercise intensity was chosen to allow participants to reach 70% HR_{max} during the recovery period) [60]. After the last interval, a cool-down period will be performed for 5 min at 30 W, totalizing 43 min of exercise. MICT and HIIT will be performed on a calibrated cycling ergometer and will be supervised by trained personnel. Exercise intensity will be controlled throughout the whole period of the training intervention. During every training session, PO, cadence, and 3-channel ECG assessing heart rate will be recorded to control for the default training intensity.

To increase adherence, the participants receive each € 500 for completing the whole study protocol. In order to secure adherence to the intervention program, they get an individually tailored training plan. Additionally, the participants receive written notifications of the diagnostic schedule before the baseline analysis. Beyond the € 500 incentive for completing the whole study protocol, adherence to training will be increased by offering two training sites and by setting fixed, yet adjustable training dates. If subjects cannot keep an appointment, an alternative date is scheduled if possible. In cases of non-appearance a telephone or direct query will be made. If a subject achieves less than 15 training sessions in the 6-week training period, the subject will be excluded from the study.

After the first 6-week training period and the repeated data collection at follow-up I, the second 6-week training period will be started without a wash-out period, therefore generating an intended carry-over effect. In the second training period, the participants have to attend to the training regime that was not selected in the previous period in order to assess whether a blunted response to the first training mode reflects a real non-response to exercise or can be counteracted by choosing an alternative exercise intensity.

3.4. Testing procedures and study protocol

Biopsychosocial data including indices of physical fitness will be collected at baseline (week 1), at follow-up I after the first training period (week 8), and at follow-up II after the second training period (week 15) (see Fig. 2). The detailed variables, which will be assessed are summarized in Table 1.

To delineate the physiological and affective response during acute exercise, a bout of cycling exercise will be performed at week 0, 8 and 15. After a 10-min warm-up at a PO corresponding to 90% of the first lactate threshold, participants will cycle at a constant PO corresponding to the midpoint between the first and the second lactate threshold for 50 min. Such exercise intensity is within the heavy-intensity domain (i. e., vigorous exercise intensity) [61] and a MET-range between 6 and 9, dependent of the individual VO_{2max}.

Venous blood samples will be drawn at baseline, week 8, and week 15 3 h prior to as well as directly and 3 h after the reference training session. A total of four muscle biopsies will be obtained from the M. vastus lateralis at baseline, week 8, and week 15 (three one day prior to and one 2 h after the reference training session – the latter only at baseline.

Biological specimens for genetic or molecular analysis are collected and stored at the Department of Sports Medicine, University Clinic Tübingen. Skeletal muscle specimens will immediately be shock-frozen in liquid nitrogen and stored at −80 °C until further use. They will be analysed for differential gene expression as well as epigenetic markers, such as DNA methylation, histone modifications, and microRNA (miRNA) patterns using standard molecular biology technologies. Serum and plasma will be aliquoted and also stored at −80 °C. These samples will be employed to determine metabolic characteristics and also to assess concentrations of circulating miRNAs.

The study is constantly monitored by physicians and trained personnel in order to prevent and manage possible adverse events and unintended effects of the interventions. All diagnostics, including potential unintended events and effects, are documented in case report forms for each participant.

In addition, we plan to document everyday activity three times, each time over a period of 7 consecutive days (at baseline, follow-up I, and follow-up II) using accelerometers.

3.5. Data analyses and statistical methods

Formally, the study uses a two-period sequential-training-intervention (STI) design with 1:1 allocation to both sequences. A computer was employed by the Institute for Clinical Epidemiology and Applied Biometry at the University of Tübingen to generate random numbers which were used to sort the cases. The allocation to the different study groups remained concealed to the researchers. The randomization list was created using the software nquery 7.0 with mixed block sizes and two binary stratification factors age (≤32/>32ys) and sex.

The primary endpoint has been chosen to be VO2max which is a physiological surrogate parameter relevant for all subsequent interdisciplinary analyses. Based on the results of this parameter, a subsequent trial with „clinically" important outcomes and a much larger sample size will be applied for funding after this study. In the terminology of clinical trials, we are in a Phase II situation, with surrogate primary endpoint, and we are generating evidence for a „Phase III-trial" on the subject. The second important parameter of general interest will be the drop-out rate compared between both sequences of interventions. This rate, however, might be biased towards overoptimistic results (too small drop-out rates in both groups) due to the honorary for successful termination of the trials for probands. For VO2max, we found in a meta-analysis of Weston et al. a delta (Baseline vs. after exercise) of 2.6 ml/kg KG/min for MICT (25.2. minus 22.5) and of 5.2 ml/kg KG/min for HIIT (27.9 minus 22.5) [62]. Thus, there was a difference of 2.6 ml/kg KG/min between both. An analysis of the standard deviations of all included study arms (calculated from sample size and standard error in Table 1 of Weston et al. [63]) showed a consistent picture of about 10% for the value of the SD (the mean of SDs was 9.46, the median 9.33, 47 of 55 study arms showed a standard deviation between 9% and 11%). Thus, we may assume a standard deviation of 10%. An effect size of 75% (for which our study was powered, see below) corresponds to 7.5%. 7.5% of 28 is 2.1

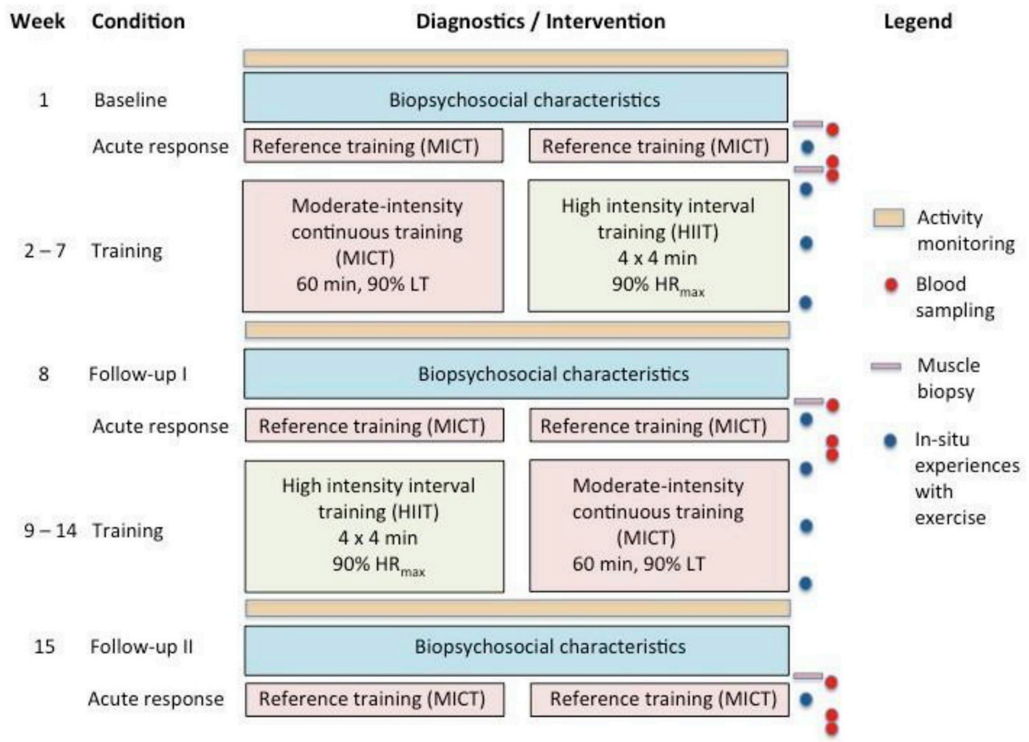

Fig. 2. Time line and protocol of the study. HR_{max}, maximal heart rate; LT, first lactate threshold.

which is close to the difference HIIT minus MICT in Weston et al. [62].

Due to the application of a sequential intervention design, a comparison of the single interventions will only be done after the first follow-up. The primary focus of our comparative longitudinal analyses is therefore on the sequences of the two interventions, not on the single interventions. Thus, the aim of the study is to identify the optimal sequence, not the optimal intervention. This leads to interindividual comparisons. With 60 subjects and two degrees of freedom spent on the strata age and sex, effect sizes (difference of means divided by standard deviation) of about 75% (exactly: 74.9%) can be show. (type 1 error 0.05, two-sided, type 2 error 0.20, nquery 7.0.). Note that the same power holds for the comparison of interventions in the first phase (secondary analysis). Adjustment for multiple testing will be difficult and will not be done across subprojects.

The analysis will be done using an Ancova with baseline as continuous covariate and sequence as factor of interest. Additionally, the stratification factors age (binary) and sex will be included in the primary analysis. As secondary analysis, a mixed model with treatment, time and the interaction as fixed and participant as random factors will be included. Note that the time vs. treatment interaction which corresponds to the (unfavourable) carry over effect in a cross over design is here part of the secondary analysis. The primary analysis population is a modified ITT population: Subjects, who do not contribute measurements from both periods will be excluded, for subjects who contribute measurements from only one period (mostly period 1) multiple imputation using the information from the documented period will be applied. As sensitivity analysis, only complete cases will be analysed. No interim analysis will be done.

3.6. *Ethic approval and consent to participate*

IRB approval: The 'Ethics Committee of the Medical Faculty, University of Tübingen' reviewed and approved this study (reference number: 882/2017BO1). All participants are informed about the study procedure, the audio recordings of interviews, subsequent data storage, and confidentiality and anonymity regarding the data. We collect written informed consent from all participants that we are allowed to use the data for research purposes and publish research articles by using a standard study consent form.

4. Study modules

4.1. *Study module 1: Individual response to physical activity as a biographical effect*

4.1.1. *Central problem*

The motivation and willingness to be physically active is shaped by the experiences people have made in their individual life world. Research about health-related *social contagion* [64] for example shows that "people imitate the diet or exercise habits of their least fit friends, or use those friends' fitness as a benchmark for their own" [[65]: p.662]. Biographical analyses can shed a light into the complexity of such activity- and health-related experiences. In this regard, they can explain why people dislike or enjoy physical activity and how behavioural patterns develop. Furthermore, the biography may have an impact on how individuals adapt on a psychosocial level to physical activity. Additionally, this module collects longitudinal data on psychosocial changes (well-being, subjective health, quality of life, and social adaption) using questionnaires (Table 1).

4.1.2. *Central research question*

Which role do biographies play regarding the individual response to physical activity?

In this regard, the project focuses on the following questions:

- How do health- and physical activity-related behavioural patterns develop across the life?
- How is physical activity perceived in the individual socio-cultural and historical life world?
- How do critical life events and transitions contribute to the uptake of or drop-out from physical activity?

Table 1
iReAct assessments.

	TIMEPOINT					
Diagnostics	t-1	t0	Training	t1	Training	t2
Week	−1	1	2–7	8	9–14	15
Assessments by Study Modules						
Screening and Study Inclusion	X					
Study Module 1						
Biographical Mapping [76,77]		X				
Psychosocial Process Monitoring [76,77]				X		X
Demographic Questionnaire [78]		X				
ALPHA Questionnaire [79]		X				
Social Support for PA Scale (adapted version) [80]		X				
Satisfaction with Life Scale [81,82]		X		X		X
WHO-Five Well-Being Index [83]		X		X		X
WHO-QOL-BREF [84]		X		X		X
Subjective Vitality Scale [85]		X		X		X
FEW-16 Questionnaire [86]						
PHQ-9 Depression Inventory [87]		X		X		X
GBB-24 Questionnaire [88]		X		X		X
Social Adaption Self-Evaluation Scale [89,90]		X		X		X
Study Module 2						
Body Scan		X				X
Biometric Body Avatars		X		X		X
Interoception Task		X		X		X
EDI-2 Questionnaire [91]		X		X		X
Drive for Thinness Scale [91]		X		X		X
Body Dissatisfaction Scale [91]		X		X		X
PACS Questionnaire [17]		X		X		X
Study Module 3						
7-Day Accelerometry (handed out before diagnostics)		X		X		X
EHIS-PAQ [92]	X			X		X
Attitudes towards Exercise Questionnaire [93]		X		X		X
Self-Determined Motivation to Exercise Questionnaire [94]		X		X		X
Exercise-Specific Self-Efficacy Questionnaire [95]		X		X		X
Motives and Goals for Exercise [96]		X		X		X
PRETIE-Questionnaire [97]		X		X		X
Activity-related Affect Regulation Questionnaire [98]		X		X		X
Affective response to reference training session (MICT)		X		X		X
Feeling Scale [99]			week 2, 4, 7		week 9, 11, 14	
Felt Arousal Scale [100]			week 2, 4, 7		week 9, 11, 14	
Enjoyment of Exercise and Perceived Competence Scale [27]			week 2, 4, 7		week 9, 11, 14	
Further determinants of subjective experience of activity (e.g., social context)			week 2, 4, 7		week 9, 11, 14	
Study Module 4						
Medical History, medical examination	X					
Anthropometry: BMI, abdominal girth; percent body fat and muscle mass (BIA)		X		X		X
Resting and exercise electrocardiogram (ECG)		X		X		X
Resting and exercise blood pressure		X		X		X
Cardiac dimensions and function (echocardiography)		X		X		X
Spiroergometry and lactate diagnostics		X		X		X
Arterial stiffness (pulse wave velocity)		X		X		X
Microvascular Endothelial Function (NIRS)		X		X		X
Blood analyses (Lipids, glucose, insulin)		X		X		X
Metabolic stress response to reference training session (plasma metabolome)		X		X		X
Training monitoring (power output, heart rate)			During training		During training	
Study Module 5						
Molecular response to reference training (muscle biopsy 2 h post-exercise)		X				
Epigenetic analyses (Resting muscle biopsies)		X		X		X

- How does the social environment (e.g. social support or networks) influence the development of health- and activity-related practices?
- Which positive and negative experiences have individuals made in different physical activity settings?
- How do individuals adapt to physical activity from a psychosocial and reconstructive health perspective? Which role does the sequence of training regimes play in this regard?

4.2. Study module 2: Body talk: Investigating changes in body image as an individual response to physical activity using biometric avatars

4.2.1. Central problem

Although cross-sectional evidence suggests an improvement of body image and interoception as an effect of physical activity, the individual response to physical activity (and specific training conditions) concerning body representation has hardly been studied. Furthermore, previous studies have predominantly relied on questionnaire data which might be less valid and sensitive to change than new approaches integrating modifiable body stimuli.

4.2.2. Central research question

The major goal is to investigate the body representation of sedentary individuals and its dynamic changes as an individual response to physical activity on a longitudinal basis.

We would like to answer the following questions:

- How is body representation of sedentary individuals characterized in terms of estimated/ideal discrepancies, body related attitudes and interoceptive performance? How are these variables associated with individual characteristics such as gender and individual biography or physiological fitness?
- How does body representation change as a response to (different types of and different sequences of different types of) physical activity?
- How are changes in body representation associated with other individual dynamic characteristics?

4.3. Study module 3: Individual affective and motivational response to different exercise regimes in sedentary adults

4.3.1. Central problem

Some researchers strongly question the potential of high intensity training for the promotion of public health. They argue that those interventions do not sufficiently reach inactive people due to the negative side-effects on affective responses to high intensity training [e.g. Refs. [66,67]]. Contrary, some interventional studies report higher enjoyment in, higher preference for and greater adherence to HIIT in contrast to MICT in insufficiently active people [67–70]. Comparably, the two recent reviews including both active and inactive people, show that HIIT can elicit similar responses on pleasure and enjoyment as MICT [71,72]. However, the authors also point out that findings are still inconsistent regarding the affective response to different exercise regimes, especially in sedentary people.

Additionally, Stork and colleagues [71] illustrate that one has to consider the time point of assessment, when drawing conclusions about affective responses to exercise. They outline: even if participants are reporting equal or greater enjoyment of, and preference for HIIT *after* the exercise is finished, affective measurements *during* the ongoing training bout appear to be more negative in HIIT than in MICT. For these in-task affective responses, evidence shows that they can be predictive of adherence and future exercise participation in continuous training [e.g. Refs. [73,74]]. Yet it is not clear if this relationship also holds for high intensity exercise regimes and if the sequence of training regimes influences the outcome.

4.3.2. Central research questions

- Comparing MICT and HIIT in a group of sedentary adults, which inter-individual and intra-individual differences occur in acute affective response during and after exercise? Does the sequence of the two interventions influence the affective response during and after exercise?
- How do these acute affective responses change over a multi-week training period? Could we observe different dynamics depending on the kind (MICT, HIIT) and the sequence of training regimes?
- Which personal (e.g. gender, individual goals) and activity-related (e.g. intensity, volume) characteristics contribute to the variability of acute affective response to exercise?
- How are exercise motivation and training adherence affected by different types and sequence of exercise regimes and corresponding affective responses to exercise?

4.4. Study module 4: Individual response to physical activity: Physical fitness, stress response and disease-related endpoints

4.4.1. Central problem

The individual response of cardiorespiratory fitness (CRF) and disease related cardiometabolic risk factors varies highly. At present, it is unclear whether the extent of trainability is based primarily on individual factors or is the result of an individual variability of the required dose of exercise. In both cases, it is desirable to obtain valid instruments which allow a prediction of the individual's training responsiveness to improve individual training counselling in the preventive setting.

4.4.2. Central research questions

The topic of study module 4 addresses the question of how the response or non-response rate in terms of physiological and disease-related risk factors to exercise training depends on the type of exercise (MICT versus HIIT) and the sequence of the two training regimes. Moreover, module 4 will elaborate, how the adaptive response is modulated by the physiological response to acute exercise and further co-variables. In particular, we will ask:

- Does non-response of physiological (e.g. physical fitness) and disease-related risk factors to MICT decline as the intensity of training increases? Does the sequence of the two interventions determine the physiological response?
- Is a different pattern of the acute stress response to a given bout of exercise related to the individual adaptive response to physical activity?
- Does gender affect the rate of low responders to two standardised training protocols (MICT, HIIT)? Does the sequence of the two interventions determine the physiological response differently dependent on gender?
- Are there gender-specific patterns of the acute stress response to a given bout of exercise which are associated with a different adaptive response to physical activity?

4.5. Study module 5: Epigenetic characteristics and changes as molecular basis for the individual response to exercise?

4.5.1. Central problem

Skeletal muscle is highly malleable and can respond to physical activity in a complex and multimodal manner. Examples of adaptation reactions are changes in muscle cell metabolism and myofibre type. The molecular basis for these adaptation reactions are altered gene expression patterns, as an individual's temporal and spatial transcriptional response to a particular type of exercise eventually determines his or her physiological response [for review, see Ref. [75]]. Most interestingly, recent work suggests that these transcriptional responses are controlled by epigenetic mechanisms, i.e. molecular mechanisms that robustly control gene expression without altering the DNA base sequence [for review, see Refs. [48,49]]. Thus, based on a refined knowledge of a possible inter-relationship between a specific type of exercise and the epigenetic reaction evoked by this regimen, it might be possible to develop individualised concepts for training programmes.

4.5.2. Central research questions

- Which types of epigenetic changes do different types of physical activity induce in the skeletal muscle? Does the sequence of the two interventions influence epigenetic changes?
- How can they or even an individual's basal epigenetic characteristics at rest be correlated with skeletal muscle transcriptional and the individual's physiological response to exercise?
- Which DNA and histone methylation patterns and which miRNA expression profiles can we observe in skeletal muscle tissue at rest and after a single bout of exercise?
- Can these patterns be correlated with expression patterns of adaptation-relevant genes, myofibre distribution, the individual's physiological response to a single bout of exercise, and/or his/her trainability, i.e. the response to a specific exercise regimen (MICT vs. HIIT) and to a specific sequence of exercise regimes?

Table 1 summarizes all assessments by study module that take place during the training intervention.

5. Discussion

To analyse the individual response to different forms of physical activity from a biopsychosocial perspective is highly relevant. Interventions, which claim to effectively and sustainably promote the individual's health, have to take into account that not every form of physical activity leads to the same responses across individuals. Likewise, not every activity is equally rewarding for a person, not at least due to his/her activity- and health-related biographical experiences and motivational prerequisites. In this regard, the expected results of the study contribute to the advancement of personalised health promotion and prevention strategies using one of the most effective instruments –

physical activity.

Ethics approval and consent to participate

Ethics approval was obtained by the 'Ethics Committee of the Medical Faculty, University of Tübingen' on the 22 January, 2018 (reference number: 882/2017BO1). All participants are informed about the study procedure, the audio recordings of interviews, subsequent data storage, and confidentiality and anonymity regarding the data. Written informed consent is collected from all participants that we are allowed to use the data for research purposes and publish research articles by using a standard study consent form.

Consent for publication

Written informed consent is collected from all participants that we are allowed to use the data for research purposes and publish research articles by using a standard study consent form.

Availability of data and material

The datasets generated and/or analysed during the current study are not publicly available. For further information, please contact the corresponding author.

Funding

The project is funded as a doctoral training network by the Ministry of Research, Science, and the Arts of Baden-Württemberg; State Postgraduate Fellowship Programme, Germany (GZ.: II.2–7631 02). The funder was not involved in study planning, study design, data collection, management, analysis, and interpretation, nor in the writing and submission of the manuscript.

We also acknowledge support for open access publication by German Research Foundation (Deutsche Forschungsgemeinschaft; DFG) and Open Access Publishing Fund of University of Tübingen.

Authors' contributions

Conceptualization and design of the study: AT, GS, BM, KG, SZ, SM, AMN. Manuscript drafting: AT, GS, AMN, HG. Statistical advisory support and generating of allocation sequence: PM. Critical revision of manuscript before submission: AT, GS, HG, FMM, TS, DS, MW, SM, PM, BM, KG, SZ, AMN. All authors read and approved the final manuscript.

Declaration of competing interest

The authors declare that they have no competing interests.

Acknowledgements

We would like to thank Yannic Pfefferlein for assisting in the formatting process.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.conctc.2019.100508.

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SYSTEMATIC REVIEW
published: 19 March 2020
doi: 10.3389/fpsyt.2020.00099

Influence of Physical Activity Interventions on Body Representation: A Systematic Review

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OPEN ACCESS

Edited by:
Josef Jenewein, Psychiatric Clinic Zugersee, Switzerland

Reviewed by:
Marwan El Ghoch, Beirut Arab University, Lebanon
Enrica Marzola, University of Turin, Italy

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Specialty section:
This article was submitted to Psychosomatic Medicine, a section of the journal Frontiers in Psychiatry

Received: *30 August 2019*
Accepted: *06 February 2020*
Published: *19 March 2020*

Citation:
Srismith D, Wider L-M, Wong HY, Zipfel S, Thiel A, Giel KE and Behrens SC (2020) Influence of Physical Activity Interventions on Body Representation: A Systematic Review. Front. Psychiatry 11:99. doi: 10.3389/fpsyt.2020.00099

Distorted representation of one's own body is a diagnostic criterion and corepsychopathology of disorders such as anorexia nervosa and body dysmorphic disorder. Previousliterature has raised the possibility of utilising physical activity intervention (PI) as atreatment option for individuals suffering from poor body satisfaction, which is traditionallyregarded as a systematic distortion in "body image." In this systematic review,conducted according to the PRISMA statement, the evidence on effectiveness of PI on body representation outcomes is synthesised. We provide an update of 34 longitudinal studies evaluating the effectiveness of different types of PIs on body representation. No systematic risk of bias within or across studies were identified. The reviewed studies show that the implementation of structured PIs may be efficacious in increasing individuals' satisfaction of their own body, and thus improving their subjective body image related assessments. However, there is no clear evidence regarding an additional or interactive effect of PI when implemented in conjunction with established treatments for clinical populations. We argue for theoretically sound, mechanism-oriented, multimethod approaches to future investigations on body image disturbance. Specifically, we highlight the need to consider expanding the theoretical framework for the investigation of body representation disturbances to include further body representations besides body image.

Keywords: body image, body representation, physical activity, eating disorders, body dysmorphic disorders

INTRODUCTION

Disturbances in body representation have been identified as the crux of many debilitating psychiatric disorders, such as body dysmorphic disorder (1), body integrity identity disorder (2), somatoparaphrenia (3), and asomatognosia (4). It has also been proposed as a core psychopathology of eating disorders [e.g., (4–9)]—especially in anorexia and bulimia nervosa. Heightened body dissatisfaction has been interpreted as a predisposition indicator in subclinical populations.

Individuals with body image concerns are reportedly more vulnerable to developing eating and dieting pathologies (10–13). As yet, however, mechanisms of change in body representation are still poorly understood, limiting mechanism-oriented interventions for prevention and treatment of disturbed body representation.

Previous literature has suggested that regular physical activity has beneficial effects on thephysical health of the body, as well as a significant impact on the level of satisfaction with whichthe body is perceived [e.g., (14–16)]. This is surprising, insofar as cross-sectional studies in individuals withhigh levels of physical activity suggest decreased rather than increased body satisfaction (17). However, it is important to note that there has been little critical appraisal of the existing studies. Previous systematic reviews and meta-analyses on the topic of physical activity and its potential interactions with body satisfaction have been conducted from an outcome-centric perspective [e.g., (14, 15, 18–20)]—focusing on evaluating the effectiveness of physical activity as an intervention for the improvement of individuals' body satisfaction—with an emphasis on the affective and cognitive aspects (i.e., body image). Nevertheless, the question of which potential mechanisms might be responsible for the apparent shift in body image after the introduction of physical activity has not been inadequately addressed.

Despite the lack of a unified consensus on its exact nature, the term body image has been widelyused in research across psychology, neuroscience, and psychiatry. Body image can roughly becharacterised as the conscious, predominantly visual, mental representation of one's own body,which in turn provides a basis upon which perceptual, cognitive, and affective attitudes toward thebody are assigned (21, 22). However, it is important to note that the current literature largely concurson the use of the term body image as a measure of body satisfaction—in that body image as anoutcome measure is interpreted as the degree with which individuals are satisfied with various aspects of themselves that is influenced by the visual aspect of their body (e.g., appraisal of body shape information). In this review, we therefore adopt the term body representation when referring to the broad range of mental representations of one's own body, whereas body image only refers to cognitive-affective appraisal of the body. The fact that body image investigations in health research has so far been conducted from an almost exclusively perceptual-affective perspective is worth discussing.

Longo (23) argued that higher level representations of thebody are unlikely to emerge from abstract cognition alone. Rather, they are constructed through theinterplay of multiple distinct body representations. Not only do individuals have immediateknowledge of their body from within (i.e., bodily awareness through interoception), they are alsoable to objectively reflect on their own body from an external perspective, in the same way thatexternal objects are cognitively assessed (with regards to their shape, size, location, aesthetics, et cetera). Relying on neuroscientific evidence, Longo's framework of body perception consists of multiple distinct body representations that are informed by different sensory modalities and can be arranged along two orthogonal axes: explicit vs. implicit & perceptual vs. conceptual. However, most empirical data concerning body image has been based on self-report or visual body size judgments, which effectively leads to the underrepresentation of other somatically driven/sensory inputs when considering the potential mechanism underlying the concept of body image (24). Although these subcomponents of body representation have been demonstrated to have distinct underpinning neural networks [see (25) for review], the mechanisms responsible for the development and regulation of these subcomponents are still very much unexplored (e.g., the idea that body satisfaction, or the lack thereof, could be socially and/or somatically driven—or the product of their interactions). As such, it is not at all clear why the body image should remain the sole focal point when investigating how individuals mentally represent their own body, and the potential distortions therein.

In this systematic review, we aim to synthesise existing literature investigating longitudinal interaction between physical activity and body image. Our purpose is to synthesise the empirical evidence from previous studies with a focus on effects, broader potential, and eventual impact mechanisms of PI on body representation. Specifically, our research questions were:

i. Are there systematic effects of PI on body representation?
ii. Are previous studies informative with regard to prevention or treatment of sub-clinical or clinically relevant body image disturbance?
iii. Are there specific mechanisms of how long-term engagement in structured PI that influence thedynamics of individuals' body representations?

METHOD

The systematic review process was conducted according to the PRISMA statement (26). Methods of analysis and inclusion criteria were specified in advance and documented in a protocol.

Literature Search

Studies were identified *via* searching the following electronic databases: PubMed, Web of Science and SPORTDiscus. The search was weekly updated until January 2020.

The specific search terms are as follows: ("body image" OR "body representation" OR "body dissatisfaction" OR "body satisfaction" OR "body image disturbance") AND ("physical activity" OR "physical exercise" OR "exercise intervention" OR "endurance training" OR "exercise training" OR "exercise intervention" OR "aerobic exercise" OR "aerobic training" OR "anaerobic exercise" OR "anaerobic training" OR "motor activity" OR "resistance training" OR "resistance exercise" OR "strength training" OR "weight training" OR "weightlifting" OR "cardio training" OR "cardio" OR "athletic sports" OR "exercise program" OR "fitness training" OR "cardiovascular training" OR "interval training" OR "intermittent training" OR "interval exercise" OR "intermittent exercise" OR "sprint training" OR "sprint exercise" OR "high intensity interval training" OR "high intensity interval exercise" OR "moderate intensity training" OR "moderate intensity exercise" OR "exercise/psychology" OR "exercise therapy/methods" OR "resistance training/methods").

Additionally, reference lists of included articles were hand searched.

Eligibility Criteria and Study Selection

Each step of the eligibility assessment was performed independently by two reviewers according to the PICOS criteria (27). Only articles in English were considered.

Studies had to fulfil the following criteria:

Population: a sample of adult participants,

Intervention: include a longitudinal physical activity intervention (PI; no lifestyle counselling; specific targeting of body image/body representation not compulsory),

Comparison/Control: include a validated measure of body image/body representation, a control group was not required,

Outcome: at least one pre & post measurement of a validated self-report or experimental body image/body representation measure, and

Study Type: published as a peer-reviewed original article.

Exclusion criteria were as follows:

i. samples younger than 18 years old, and
ii. no inference statistics performed.

The first author (DS) applied the search terms to three databases, extracted the search results and removed duplicates. DS and LW screened titles to identify relevant records. Abstracts and full texts of the identified records were subsequently screened by DS and SB. All studies included in the qualitative synthesis were rated according to the eligibility criteria by DS and SB. Interrater reliability between DS and LW for title screening was good (κ = 0.61; 94.2% agreement). Articles were included in the full-text screening if one reviewer rated it as a potential match. Interrater reliability between DS and SB for the subsequent steps was very good (κ = 1.0 for abstract screening; κ = 0.94 for full-text screening). Disagreements between the reviewers were solved by discussion and, when in doubt, articles were included. DS extracted relevant data from the included studies (i.e., sample characteristics, PI types and dosage, measure of fitness level, measures of body composition, measures of body image/body representation, and results).

Risk of Bias in Individual Studies

To assess the risk of bias in individual studies, DS and SB conducted a quality rating. The Qualitative Assessment Tool for Quantitative Studies by the Effective Public Health Practice Project (28, 29) is recommended by the Cochrane Handbook for Systematic Reviews of Interventions to be used for assessing any quantitative study design (30) and was judged a suitable tool for systematic reviews of effectiveness (31). The tool consists of component ratings for the following categories: selection bias, study design, confounders, blinding, data collection methods, and withdrawals and dropouts. Components were rated according to the accompanying dictionary. Studies received ratings of either "strong", "moderate", or "weak" for each category. A global rating was assigned at the end of the process *via* the summarisation of the number of categories rated as "weak". Disagreements between the reviewers were solved by discussion.

RESULTS

Study Selection

The searches yielded a total of 3,318 results. Duplicates were discarded (n = 602), leaving 2,716 records for title and abstract screening. During this process, 2,659 studies were discarded, and the remaining 57 studies were identified for full-text analysis. Subsequently, 34 studies were included in the systematic review. For the PRISMA flow chart, see **Figure 1**.

Study Quality

The overall study quality within the current review showed a slight majority for "weak" (55.88%; n = 19), followed by "moderate" (41.17%; n = 14). Only 1 study (2.94%) included in the review qualified for the global "strong" rating. The detailed components ratings are included in **Table 1**.

Notably, included studies only received weak (n = 26) and moderate (n = 8) ratings for the selection bias category. The main reason for depreciation was the recruitment in sports classes or from community samples; thus producing a selection bias favouring highly motivated, sports-oriented participants. In the same vein, most studies qualified for moderate rating in the study design category (n = 27). This is due to the lack of randomisation in the selection as well as group allocation process, as participants often conducted the PI of their choice. This limits explanatory power regarding general recommendations of effective types of training. To summarise, there is a possibility for risk of bias in the studies included in the current review.

Study Characteristics

The study characteristics of included studies are detailed in **Table 1**. All studies employed a longitudinal design, as defined by the inclusion criteria. Of the total 34, 6 studies were described as quasi-experimental. Twenty-three studies included control groups in their experimental design, while the remaining 11 did not. Within the 23 controlled studies, 18 studies included "no intervention" comparison groups, while the remaining 5 studies included participants who performed low to moderate exercise as controls. Eight studies included clinical and/or sub-clinical groups. The remaining 26 studies had healthy samples. Eleven studies aimed to compare different types of PIs and their impact on body image/body representation of participants. Most studies (n = 27) did not have a randomised participant selection and/or group allocation process.

Physical Activity Interventions

The most commonly investigated types of PI were weight/strength training (n = 14), as well as aerobics/cardiovascular training (n = 13). Three studies implemented the combination of

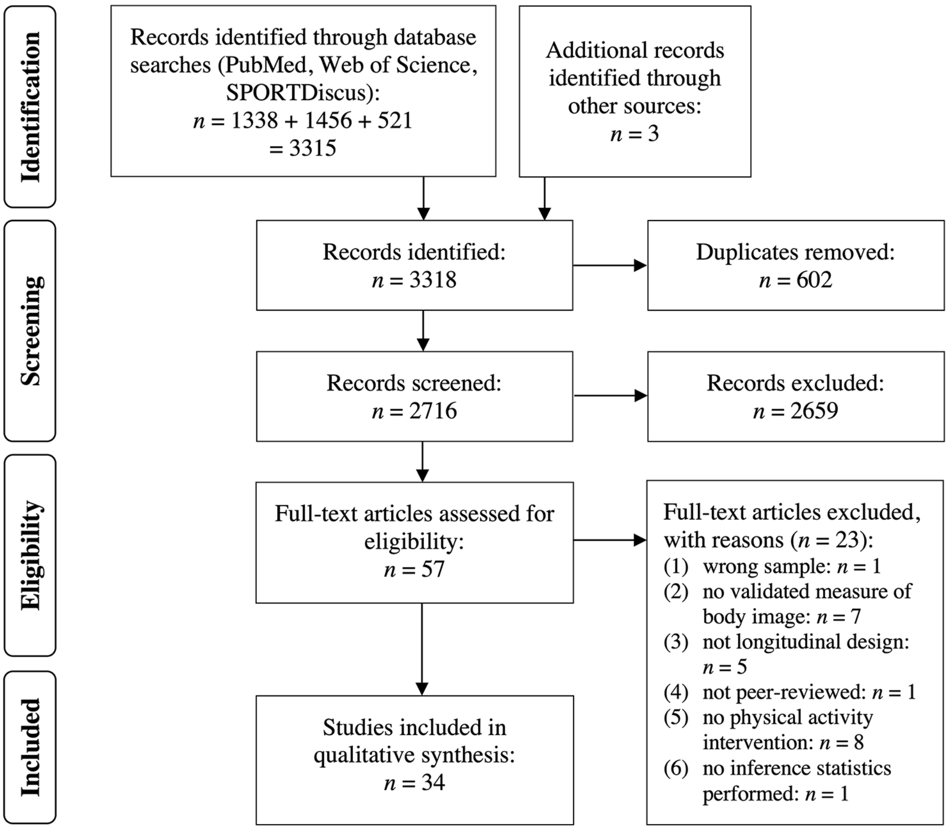

FIGURE 1 | PRISMA flowchart for study selection.

both types as a singular intervention. Dancing (n = 3) was also investigated. Other PIs included walking, running, swimming, cycling, pilates, hydrogymnastics, yoga, fascial fitness, and functional training. The mean length of time for the implementation of the PI was 13.29 (SD = 8.45) weeks, with the maximum of 52 weeks (1 year) and the minimum of 2 weeks. The median for PI duration was 12 weeks.

VO_2max was used as a measure of fitness in 9 studies. Eleven studies conducted strength tests as a marker of fitness level (i.e., variations of maximum repetition test). Heartrate was also measured as a marker of fitness level (n = 4). Twelve studies did not report any measure of physical fitness.

Outcome Measures

Studies were homogeneous in terms of the operationalisation of body image/body representation measures. Almost all studies exclusively implemented validated questionnaires assessing body image. Only 3 studies additionally implemented more visual-oriented measures (i.e., Stunkard Scale of Silhouette, Figure Rating Scale)—though nevertheless still affective/subjective in nature. No study used experimental assessments of body representation (e.g., depictive/metric body size and visual estimation tasks). As such, the domains of visual, tactile and affordance perception of body representation were not at all investigated.

The most commonly employed scales were MBSRQ (Multidimensional Body Self-Relations Questionnaire; (66) and PSPP (Physical Self-Perception Profile; (67) at 23.53% (n = 8) each. The Body Cathexis Scale was also frequently implemented in earlier studies (n = 7; 20.59%; (68).

Systematic Effects of PI on Body Representation

PI was considered effective if significant improvement in body representation measures was reported at post-test among the intervention group, relative to the control group. The overall results are as follows: 5 studies (14.71%) observed no significant improvement in both control and PI groups across all body image measures; 3 studies (8.82%) observed significant improvement in both control and PI groups across all body image measures; 10 studies (29.41%) reported significant improvement in PI group across all body image measures; 16 studies (47.06%) reported partial significance effect in PI groups (i.e., not all improvement in scores measured in the subscales of the implemented questionnaires reached significance).

However, due to the low number of clinical and sub-clinical studies (n = 8) included in this systematic review, we cannot reliably synthesise significant evidence with regard to utilising long-term PI (structured or otherwise) as a treatment measure for clinically relevant groups.

TABLE 1 | Overview on main characteristics and findings of included studies.

Study	Sample characteristics	*n*	Physical activity intervention & dosage	Measure of fitness level	Measure of body composition	Measure of body image/ representation	Main findings	Quality rating: Global rating	Selection bias	Study design	Confounders	Blinding	Data collection methods	Withdrawal and dropouts
								Strong ○ Moderate ● Weak ●						
Folkins (32) ◊	M_{age}: *n. r.* M_{BMI}: *n. r.* % Female: 0% ※At high-risk of coronary heart disease **Controls:** no intervention	18 18	Unspecified 36x *n. r.* minutes over 12 weeks	VO_2max	N/A	BCS	**PI & Control Groups** • There were no significant changes in BCS scores post-test for both groups.	○ (Strong)	● (Moderate)	● (Moderate)	○ (Strong)	● (Moderate)	○ (Strong)	○ (Strong)
Tucker (33) ◊	M_{age}: *n. r.* M_{BMI}: *n. r.* % Female: 0% **Controls:** no intervention	60 45	Weight training 32x 50 minutes over 16 weeks	N/A	N/A	TSCS	**PI Group** • Showed significant increase from pre to post PI on all TSCS indices except Social Self. • Scored significantly higher than control group in the Total Positive, Identity, Behaviour, Physical Self, and Personal Self indices of TSCS post PI. **Control Group** • There were no significant changes in TSCS scores post-test. ※PI and control groups did not differ significantly in Moral-Ethical Self, Self-Satisfaction, Family Self, or Social Self indices post-test.	● (Moderate)	● (Moderate)	● (Moderate)	● (Weak)	● (Moderate)	○ (Strong)	○ (Strong)

(Continued)

TABLE 1 | Continued

Study	Sample characteristics	*n*	Physical activity intervention & dosage	Measure of fitness level	Measure of body composition	Measure of body image/ representation	Main findings	Quality rating: Global rating	Selection bias	Study design	Confounders	Blinding	Data collection methods	Withdrawal and dropouts
								Strong ○ Moderate ● (grey) Weak ●						
Tucker (34) ◊	M_{age}: *n. r.* M_{BMI}: *n. r.* % Female: 0%	142	Strength (weight) training 32x 50 minutes over 16 weeks	Strength test	N/A	BCS, TSCS	**PI Group** • Scored significantly higher than control group for both BCS and TSCS measures post PI.	Weak	Moderate	Moderate	Weak	Moderate	Strong	Weak
	Controls: no intervention	130					**Control Group** • There were no significant changes in BCS and TSCS scores post-test.							
Tucker (35) ◊	M_{age}: *n. r.* M_{BMI}: *n. r.* % Female: 0%	114	Weight training 32x *n. r.* minutes over 16 weeks	1-RM strength test		BCS	**PI Group** • Scored significantly higher than control group for BCS post PI.	Moderate	Moderate	Moderate	Moderate	Moderate	Strong	Weak
	Controls: no intervention	127					**Control Group** • There were no significant changes in BCS scores post-test.							
Caruso and Gill (36) ◊	Study 1 M_{age}: *n. r.* M_{BMI}: *n. r.* % Female: 100%	13	Weight training	1-RM strength test, VO_2max	Body fat % (skinfold measures at 3 sites)	PSPP, PIP, BCS	**PI & Control Groups** • PSPP, PIP and BCS scores improved post-test (significance not calculated) but did not significantly differ between groups.	Weak	Weak	Moderate	Weak	Moderate	Strong	Weak
		15	Aerobic training 30x 50 minutes over 10 weeks											
	Controls: physical education activity class	6												
	Study 2 M_{age}: *n. r.* M_{BMI}: *n. r.* % Female: 45.2%	42	Weight training 30x 50 minutes over 10 weeks	Max. repetition strength test	Body fat % (skinfold measures at 3 sites)	PSPP, PIP, BCS, BES, Stunkard Scale of Silhouette	**PI & Control Groups** • PSPP, PIP, BCS, BES scores and Body Size Drawings revealed no							

(Continued)

TABLE 1 | Continued

Study	Sample characteristics	*n*	Physical activity intervention & dosage	Measure of fitness level	Measure of body composition	Measure of body image/ representation	Main findings	Quality rating: Global rating	Selection bias	Study design	Confounders	Blinding	Data collection methods	Withdrawal and dropouts
	Controls: non-fitness activity	23					significant changes post-test for both groups.							
Tucker and Maxwell (37) ◊	M_{age}: *n. r.* M_{BMI}: *n. r.* % Female: 100%	60	Weight training 30x 45 minutes over 15 weeks	1-RM strength test	Body fat % (skinfold measures at 3 sites)	BCS	**PI Group** • Scored significantly higher than control group for BCS post PI (after controlling for pre-test differences). • Showed significantly greater improvement than control group from pre-test to post-test on BCS scores.	Weak	Moderate	Moderate	Weak	Moderate	Strong	Weak
	Controls: exercised 2.9 ± 2.2 days/week; no weight training	92					**Control Group** • Showed no significant improvement from pre-test to post-test on BCS scores.							
Tucker and Mortell (38) ◊	M_{age}: 42.5 ± 4.2 M_{BMI}: *n. r.* % Female: 100%	30	Weight training	Max. repetition & 1-RM strength test, 1 Mile Walk test	N/A	BCS	**PI Groups** • Both groups showed significant improvement in BCS scores post PI. • Weight-trainers scored significantly higher than walkers on BCS scores post PI.	Weak	Weak	Moderate	Weak	Moderate	Strong	Strong
		30	Walking program 36x *n. r.* minutes over 12 weeks											
	Controls: none													
McAuley et al. (39) ◊	M_{age}: 54.5 M_{BMI}: *n. r.* % Female: 50.6%	83	Aerobic training	VO_2max	Body fat % (skinfold measures at 3 sites)	PSPP, PIP	**PI Group** • Significant improvements were found in the	Moderate	Weak	Moderate	Moderate	Moderate	Strong	Moderate

Quality rating: Strong ○ Moderate ● Weak ●

(Continued)

TABLE 1 | Continued

Study	Sample characteristics	*n*	Physical activity intervention & dosage	Measure of fitness level	Measure of body composition	Measure of body image/ representation	Main findings	Quality rating: Global rating	Selection bias	Study design	Confounders	Blinding	Data collection methods	Withdrawal and dropouts
	Controls: none		60x 40 minutes over 20 weeks				following subscales of PSPP: Physical Self-Worth & perceptions of Physical Condition. • Attractive Body subscale of PSPP rating showed no significant effect post-test.							
McAuley et al. (40) ◊	M_{age}: 66.71 ± 5.35 M_{BMI}: *n. r.* % Female: 71.8% **Controls:** none	85 89	Aerobic training Toning exercise 72x 40 minutes over 24 weeks	VO_2max, heartrate	Body fat % (TOBEC)	PSPP	**PI Groups** • Latent growth curve analyses showed a curvilinear pattern of growth with significant increases at all levels of PSPP measure upon completion of PI. • Significant declines were shown at 6 months post PI in both groups.	Moderate ●	Weak ●	Strong ○	Moderate ●	Moderate ●	Strong ○	Strong ○
Williams and Cash (41) ◊	M_{age}: 21.7 ± 3.8 M_{BMI}: 23.9 ± 4.4 % Female: 69.2% **Controls:** no intervention	39 39	Weight training 1x 180 minutes over 6 weeks	1-RM strength test	N/A	MBSRQ, SPAS	**PI Group** • Showed significant improvement post PI in SPAS scores, as well as Appearance Evaluation and Body Area Satisfaction subscales of MBSRQ. **Control Group** • Reported no significant changes	Weak ●	Weak ●	Moderate ●	Weak ●	Moderate ●	Strong ○	Strong ○

Strong ○ Moderate ● Weak ●

(Continued)

TABLE 1 | Continued

Study	Sample characteristics	*n*	Physical activity intervention & dosage	Measure of fitness level	Measure of body composition	Measure of body image/ representation	Main findings	Quality rating: Global rating	Selection bias	Study design	Confounders	Blinding	Data collection methods	Withdrawal and dropouts
							on all measures post-test. ⋇After adjusting for pre-test score differences, significant group differences were found for Appearance Evaluation, Body Area Satisfaction and Social Physique Anxiety post-test.							
Aşçı (42) ◊	M_{age}: 22.15 ± 1.87 M_{BMI}: *n. r.* % Female: 52.9% **Controls:** no intervention	70 68	Step dance 30x 50 minutes over 10 weeks	N/A	N/A	PSPP	**PI & Control Groups** • PI group showed significantly greater improvement than control group from pre-test to post-test on all PSPP subscales except for Sport Competence.	●	●	○	●	•	○	○
Aşçı (43) ◊	M_{age}: 21.35 ± 0.88 M_{BMI}: *n. r.* % Female: 100% **Controls:** no intervention	20 20	Aerobic training & step dance 30x 50 minutes over 10 weeks	N/A	N/A	PSDQ	**PI & Control Groups** • Participants in the PI group showed significant improvement in Physical Activity, Coordination, Sport Competence and Flexibility subscales of PSDQ as compared the control group post-test.	●	●	○	●	•	○	○

Quality rating: Strong ○ Moderate • Weak ●

(Continued)

TABLE 1 | Continued

Study	Sample characteristics	*n*	Physical activity intervention & dosage	Measure of fitness level	Measure of body composition	Measure of body image/ representation	Main findings	Quality rating: Global rating	Selection bias	Study design	Confounders	Blinding	Data collection methods	Withdrawal and dropouts
								Strong ○ Moderate ◐ Weak ●						
Depcik and Williams (44) ◊	M_{age}: 22.13 ± 5.51 M_{BMI}: *n. r.* % Female: 100% ⋇Pre-existing body image disturbance (109.0 mean group score on BSQ) **Controls:** exercised 2.23 ± 2.02 days/ week; no weight training	15 15	Resistance (weight) training 52x 50 minutes over 13 weeks	1-RM strength test	N/A	BCS, BSQ	**PI & Control Groups** • Mean BCS scores significantly increased for weight trainers as compared to control group post-test. • The groups differed significantly in body image disturbance (BSQ scores) post-test. Weight trainers experienced a greater reduction in body image disturbance than control group post-test.	●	●	◐	●	◐	○	○
Annesi (45) ◊	M_{age}: *n. r.* M_{BMI}: *n. r.* % Female: 100% **Controls:** no intervention	48 30	Cardiovascular training 36x 30 minutes over 12 weeks	N/A	N/A	BES	**PI & Control Groups** • Scores on the Physical Condition subscale of BES significantly increased post-test for the exercise group, but not the control group. • Scores on the Sexual Attractiveness subscale of BES did not significantly change post-test for both groups.	◐	●	◐	◐	◐	○	○
Annesi and Westcott (46) ◊	M_{age}: 46.3 ± 13.4 M_{BMI}: *n. r.* % Female: 50.6%	35	Weight & cardiovascular training	Heartrate	N/A	PSPS	**PI Group** • PSPS scores significantly improved post PI.	●	●	◐	●	◐	○	○

(Continued)

TABLE 1 | Continued

Study	Sample characteristics	*n*	Physical activity intervention & dosage	Measure of fitness level	Measure of body composition	Measure of body image/ representation	Main findings	Quality rating: Global rating	Selection bias	Study design	Confounders	Blinding	Data collection methods	Withdrawal and dropouts
								Strong ○ Moderate ● Weak ●						
	Controls: none		30x 60 minutes over 10 weeks											
Ginis et al. (47) ◊	M_{age}: 21.57 ± 2.47 M_{BMI}: *n. r.* % Female: 36.4% **Controls:** none	44	Strength (weight) training 60x *n. r.* minutes over 12 weeks	1-RM test	Body fat % (DXA)	SPAS, BASS, DMS	**PI Group** • Participants experienced significant increases in BASS and decreases in SPAS scores post PI. • Only male participants experienced a significant decrease in muscularity dissatisfaction (DMA score) post PI.	● [Moderate]	● [Moderate]	● [Moderate]	● [Weak]	● [Moderate]	○	○
Hős (48) ◊	M_{age}: 48.9 ± 5.6 M_{BMI}: *n. r.* % Female: 100% **Controls:** no intervention	25 28	Aerobic dance 52x 60 minutes over 52 weeks	N/A	N/A	TSIT	**PI Group** • Showed significant increases post PI on Total Self-Image (all subscales of TSIT, except for Family Self-Image). **Control Group** • There were no significant changes post-test on Total Self-Image (all subscales of TSIT, except for Social Self-Image). ※There were significant differences between	● [Weak]	● [Weak]	● [Moderate]	● [Weak]	● [Moderate]	○	○

(Continued)

TABLE 1 | Continued

Study	Sample characteristics	*n*	Physical activity intervention & dosage	Measure of fitness level	Measure of body composition	Measure of body image/ representation	Main findings	Quality rating: Global rating	Selection bias	Study design	Confounders	Blinding	Data collection methods	Withdrawal and dropouts
								Strong ○ Moderate ◍ Weak ●						
							both groups on all subscales of TSIT post-test, except for Social Self-Image.							
Henry et al. (49) ◊	M_{age}: 19.24 ± 1.43 M_{BMI}: 22.85 ± 3.39 % Female: 100%	23 28	Aerobic training Interval cuircuit (weight) training 36x 50 minutes over 12 weeks	Step test (VO_2max), bench press test (muscular strength & endurance)	Body fat % (skinfold measure at 3 sites)	BSIQ	**PI & Control Groups** • Interval circuit training group improved significantly post PI in overall Appearance Evaluation and Health/Fitness Evaluation & Influence, as well as significantly reduced Negative Affect subscales of the BSIQ as compared to control group.	●	●	◍	●	◍	○	○
	Controls: low to moderate exercise (3.24 days/week)	21												
Opdenacker et al. (50) ◊	M_{age}: 66.65 ± 4.16 M_{BMI}: 27.08 ± 19.11 % Female: *n. r.*	46 49	Lifestyle PI Structured exercise 33x 60-90 minutes over 11 weeks	VO_2max	N/A	PSPP	**PI & Control Groups** • Immediately after PI, the lifestyle group showed significant improvements in Self-Perceived Physical Condition, Body Attractiveness, and Physical Self-Worth subscales of PSPP. In the structured group, significant effects were found on only on Physical Condition. • One year after PI, the lifestyle group had significant	◍	●	◍	◍	◍	○	◍
	Controls: no intervention	46												

(Continued)

TABLE 1 | Continued

Study	Sample characteristics	*n*	Physical activity intervention & dosage	Measure of fitness level	Measure of body composition	Measure of body image/ representation	Main findings	Quality rating: Global rating	Selection bias	Study design	Confounders	Blinding	Data collection methods	Withdrawal and dropouts
							effects on Body Attractiveness while the structured group showed significant improvements in Physical Condition and Body Attractiveness. ※There were no significant differences between PI groups for both short and long-term results.							
Özdemir et al. (51) ◊	M_{age}: *n. r.* M_{BMI}: *n. r.* % Female: 0% **Controls:** no intervention	11 11 11 12	Swimming Cycling Running 36x 40 minutes over 12 weeks	VO_2max	Body fat % (DEXA), muscular strength (isokinetic dynamometer),	PSPP	**PI & Control Groups** • All groups revealed no statistical improvement in PSPP scores post-test.	● (Moderate)	● (Moderate)	○ (Strong)	● (Weak)	● (Moderate)	○ (Strong)	○ (Strong)
Cruz-Ferreira et al. (52) ◊	M_{age}: 41.08 ± 6.64 M_{BMI}: *n. r.* % Female: 100% **Controls:** no intervention	38 24	Pilates 48x 60 minutes over 24 weeks	N/A	N/A	PSCS	**PI Group** • Showed significant improvement between baseline and 6 months post PI in Perception of Physical Appearance, Functionality and Total Physical Self-Concept. **Control Group** • No significant differences were observed over time.	● (Moderate)	● (Weak)	○ (Strong)	● (Moderate)	○ (Strong)	○ (Strong)	● (Moderate)

Strong ○ Moderate ● Weak ●

(Continued)

TABLE 1 | Continued

Study	Sample characteristics	*n*	Physical activity intervention & dosage	Measure of fitness level	Measure of body composition	Measure of body image/ representation	Main findings	Quality rating: Global rating	Selection bias	Study design	Confounders	Blinding	Data collection methods	Withdrawal and dropouts
								Strong ○ Moderate ◍ Weak ●						
							※No significant differences in PSCS scores were observed between groups at all time points.							
Moore et al. (53) ◊	M_{age}: 20.2 ± 2.02 M_{BMI}: *n. r.* % Female: 30.8% **Controls:** none	120	Resistance (weight) training 24x *n. r.* minutes over 12 weeks	1-RM strength test	N/A	PSPS, PSAQ	**PI Group** • Significant improvements were observed across all measures post PI.	●	●	◍	●	◍	○	○
Van Puymbroeck et al. (54) ◊	M_{age}: 58.67 ± 9.82 M_{BMI}: *n. r.* % Female: 100% ※≥9 months post breast cancer treatment **Controls:** light exercise	18 12	Hatha yoga 16x 75 minutes over 8 weeks	Tests for flexibility, strength, abdominal muscular endurance, agility & dynamic balance	N/A	Body Image Scale for use with cancer patients	**PI & Control Groups** • PI group reported significantly more positive body image as compared to control group at pre and post-test. • There were no statistical differences for the changes in body image scores over time for both groups.	●	●	◍	●	◍	○	◍
Appleton (55) ◊	M_{age}: *n. r.* M_{BMI}: *n. r.* % Female: 52.9% **Controls:** within-subjects,	34 34	Cardiovascular training 12x 40 minutes over 2 weeks	N/A	Body weight, waist & hip circumferences	MBSRQ	**PI Group** • There were significant increases in the following subscales of MBSRQ: Appearance Evaluation, Fitness	◍	●	◍	◍	◍	○	○

(Continued)

TABLE 1 | Continued

Study	Sample characteristics	*n*	Physical activity intervention & dosage	Measure of fitness level	Measure of body composition	Measure of body image/ representation	Main findings	Quality rating: Global rating	Selection bias	Study design	Confounders	Blinding	Data collection methods	Withdrawal and dropouts
								Strong ○ Moderate ● (grey) Weak ●						
	no intervention (12x 40 minutes reading over 2 weeks)						Evaluation, Fitness Orientation, Health Evaluation, Illness Orientation and Body Areas Satisfaction; Self-Classified Weight significantly decreased post PI. **Control Group** • Appearance Evaluation and Body Areas Satisfaction subscales of MBSRQ significantly decreased during no PI condition. ※Appearance Orientation, Health Orientation and Overweight Preoccupation subscales of MBSRQ were unaffected by PI.							
Hatipoglu et al. (56) ♦	M_{age}: 45.63 ± 8.12 M_{BMI}: 33.2 % Female: 18.2% ※Acromegaly patients **Controls:** no intervention	11 9	Cardiovascular, strength, balance & stretching training 36x 75 minutes over 12 weeks	N/A	BMI	MBSRQ	**PI Group** • Significant improvement in MBSRQ scores was observed post PI. **Control Group** • No significant changes in MBSRQ scores were reported post-test.	●	●	● (grey)	● (grey)	● (grey)	○	●

(Continued)

TABLE 1 | Continued

Study	Sample characteristics	*n*	Physical activity intervention & dosage	Measure of fitness level	Measure of body composition	Measure of body image/ representation	Main findings	Quality rating: Global rating	Selection bias	Study design	Confounders	Blinding	Data collection methods	Withdrawal and dropouts
								Strong ○ Moderate ◐ Weak ●						
Pearson and Hall (57) ♦	M_{age}: 33.4 ± 7.6 M_{BMI}: 29.02 ± 4.71 % Female: 100% ⋇Obesity patients (BMI >25 kg/m^2) **Controls:** none	37	Cardiovascular training 54x 45 minutes over 18 weeks	VO_2max	Waist circumference, body weight & fat % (DXA)	MBSRQ	**PI Group** • Significant improvements occurred between baseline and week 6 as well as week 18 post PI for Appearance Evaluation, Fitness Orientation and Body Areas Satisfaction subscales of MBSRQ.	●	◐	◐	●	◐	○	●
Seguin et al. (58) ◊	M_{age}: 62 ± 12 M_{BMI}: *n. r.* % Female: 100% **Controls:** none	341	Strength (weight) training 20x 60 minutes over 10 weeks	N/A	N/A	MBSRQ	**PI Group** • Significant improvement occurred post PI for Health Orientation, Subjective Weight, Fitness Orientation, Fitness Evaluation, and Health Evaluation subscales of MBSRQ. • There were no significant changes in Weight Preoccupation subscale of MBSRQ post PI.	◐	●	◐	○	◐	○	◐
Zarshenas et al. (59) ◊	M_{age}: 26 ± 6.9 M_{BMI}: *n. r.* % Female: 100% ⋇Pre-exisiting self-reported mild to severe depressive symptoms (BDI-II score of ≥14)	41	Aerobic training *n. r.*x 65 minutes over 4 weeks	Heartrate	N/A	MBSRQ	**PI Group** • MBSRQ scores across all subscales significantly improved post PI. • Significant improvement was found in Appearance Evaluation,	●	●	◐	◐	◐	○	●

(Continued)

TABLE 1 | Continued

Study	Sample characteristics	*n*	Physical activity intervention & dosage	Measure of fitness level	Measure of body composition	Measure of body image/ representation	Main findings	Quality rating: Global rating	Selection bias	Study design	Confounders	Blinding	Data collection methods	Withdrawal and dropouts
	Controls: no intervention	41					Appearance Orientation, Health Orientation, and Illness Orientation subscales of MBSRQ post PI as compared to control group. **Control Group** • There were no significant changes in MBSRQ scores post-test.							
Ginis et al. (60) ◊	M_{age}: 21.5 ± 2.93 M_{BMI}: 22.96 ± 3.89 % Female: 100% ※Pre-existing body image concerns (≥27 score on SPAS & ≤3 on BASS) **Controls:** none	17 23	Aerobic training Strength training 24x 45 minutes over 8 weeks	VO_2max, 10-RM strength test	BMI, waist-hip ratio	SPAS, AE, BASS, PSDQ	**PI Groups** • Both PI groups revealed significant improvements across all measures post PI. • Aerobic training group yielded significantly greater improvements in SPAS as compared to strength training group post PI.	Moderate	Weak	Moderate	Moderate	Moderate	Strong	Strong
Mendonça et al. (61) ◊	M_{age}: *n. r.* M_{BMI}: *n. r.* % Female: 100% **Controls:** no intervention	25 28 21 25	Strength (weight) training Dance Hydrogymnastics 48x 60 minutes over 16 weeks	8-RM strength test, heart rate	N/A	SPA, Stunkard Scale of Silhouette	**PI and Control Groups** • Significant improvements in SPA scores were found regardless of the program, with the greatest effect shown by the strength training group post PI. • No significant differences were found for body image	Weak	Weak	Strong	Weak	Moderate	Strong	Weak

Quality rating: Strong ○ Moderate ● (grey) Weak ● (black)

(Continued)

TABLE 1 | Continued

Study	Sample characteristics	*n*	Physical activity intervention & dosage	Measure of fitness level	Measure of body composition	Measure of body image/ representation	Main findings	Quality rating: Global rating	Selection bias	Study design	Confounders	Blinding	Data collection methods	Withdrawal and dropouts
							perception and bodily dissatisfaction post PI. • All PI groups showed significant improvements across all measures when as compared to control group post-test.							
Vurgun (62) ◊	M_{age}: 40.5 ± 12.1 M_{BMI}: *n. r.* % Female: 100% **Controls:** no intervention	12 20	Aerobic training 42x 60 minutes over 14 weeks	Heartrate	BMI, waist-hip ratio, body density and fat ratio (skinfold measured at 9 sites)	BISQ	**PI and Control Groups** • BISQ scores were significantly improved post PI as compared to control group.	◍	●	◍	◍	◍	○	○
Baur et al. (63) ◊	M_{age}: 37.9 ± 9.2 M_{BMI}: *n. r.* % Female: 52.8% ※Suffers from non-specific back pain **Controls:** none	17	Fascial* fitness 3x 60 minutes over 3 weeks	N/A	N/A	FKB-20	**PI groups** • Fascial fitness group showed significant improvement only for negative body image post PI.	●	●	◍	●	◍	○	○
Megakli et al. (64) ♦	M_{age}: 32.70 ± 7.26 M_{BMI}: 35.84 ± 4.59 % Female: 100% ※ Obesity patients (BMI >30 kg/m^2) **Controls:** no intervention	18 19	Aerobic & resistance training 36x 30 minutes over 12 weeks	N/A	Waist & hip circumferences	PSPP	**PI and Control Groups** • PI group showed significant increases post PI for all PSPP subscale scores except for Perceived Body Attractiveness as compared to control group.	◍	●	○	○	◍	○	○

Quality rating: Strong ○ Moderate ◍ Weak ●

(Continued)

TABLE 1 | Continued

Study	Sample characteristics	n	Physical activity intervention & dosage	Measure of fitness level	Measure of body composition	Measure of body image/ representation	Main findings	Quality rating: Strong ○ Moderate ◐ Weak ● — Global rating	Selection bias	Study design	Confounders	Blinding	Data collection methods	Withdrawal and dropouts
Aukštuolytė et al. (65) ◇	M_{age}: 35.58 M_{BMI}: *n. r.* % Female: 100% **Controls:** none	15 16	Functional training Zumba 16x 60 minutes over 8 weeks	N/A	Body fat % (skinfold measure at 4 sites)	BSQ, Figure Rating Scale	**PI Groups** • Body shape dissatisfaction was significantly reduced for functional training group after PI, but not for Zumba group.	●	●	◐	●	◐	○	●

Symbols: *[◆] Clinical sample; [◈] Sub-clinical sample; [◇] Non-clinical sample.*
Abbreviations: *Not Applicable (N/A); Not Reported (n.r.); Physical Activity Intervention (PI).*
Abbreviated Measures: *Appearance Evaluation (AE) sub-scale of MBSRQ; Beck's Depression Inventory-second edition (BDI-II); Body Areas Satisfaction (BASS) sub-scale of MBSRQ; Body Cathexis Scale (BCS); Body Esteem Scale (BES); Body Image Satisfaction Questionnaire (BISQ); Body Self-Image Questionnaire (BSIQ); Body Shape Questionnaire (BSQ); Drive for Muscularity Scale (DMS); Fragebogen zum Körperbild (FBK-20 aka. Body Image Questionnaire (BIQ)); Multidimensional Body Self-Relations Questionnaire (MBSRQ); Perceived Importance Profile (PIP); Physical Self-Attribute Questionnaire (PSAQ); Physical Self-Concept Scale (PSCS) subscale of the TSCS; Physical Self-Description Questionnaire (PSDQ); Physical Self; Perception Profile (PSPP); Physical Self-Perception Scale (PSPS) subscale of the TSCS; Satisfaction with Physical Appearance Scale (SPA); Social Physique Anxiety Scale (SPAS); Tennessee Self Concept Scale (TSCS); Tennessee Self Image Test (TSIT).*
**The Structural Integration group from (63) is not taken into consideration, as structural integration is not considered as a physical activity intervention, rather a form of physical therapy.*

Mechanisms Underpinning the Interplay Between PI and Body Representation

All studies included neither explicitly addressed/proposed a form of a mechanistic interplay between PI and body representation, nor provided evidence to support one. As such, the question of which potential mechanisms might be responsible for the apparent shift in body representation after the introduction of physical activity remain inadequately addressed.

DISCUSSION

In this systematic review, we synthesised the empirical findings from longitudinal intervention studies on effects of structured PI on body representation. Overall, the studies suggest that the implementation of structured PI is associated with improved body image. Effects on other body representations were not investigated. To our knowledge, this review is the first to demonstrate such an effect in longitudinal settings. The effectiveness of these interventions seems promising for future research and possible development of prevention interventions. However, we argue that due to the quality of existing studies, further research is highly necessary to investigate whether the positive effects of PI can be generalised across healthy (active or sedentary), sub-clinical as well as clinical populations, and to capture a more complete sense of body representations that allows for exploring potential mechanisms of change.

Based on the evidence available, PI can be cautiously regarded as a potentially effective option regarding body image related outcomes. Notably, the studies included in the review examined predominantly volunteer groups (i.e., people who were generally open to the idea of engaging in physical activity), even if they were previously sedentary. It remains unclear whether positive effects of PI would also generalise to the voluntarily sedentary population who are physical-activity-reluctant. From a clinical perspective, these groups would be very relevant, since they are at higher risk for cardiovascular diseases and obesity. Thus, from the current studies, it remains unclear whether PI can be recommended as a general treatment to people suffering from poor body image.

Based on our systematic review, it would not be responsible to simply conclude that PI might be a promising treatment option for sub-clinical and/or clinical populations whose core psychopathology is centred around body dissatisfaction and distorted representation of one's own body. Despite the fact that a general improvement in measures of body representations can be observed, the percentage of clinical and sub-clinical studies included within the systematic review is too low to draw such a conclusion (23.53%). Additionally, there is no clear evidence regarding an additional or interactive effect of PI when implemented in conjunction with established treatments for clinical populations. More importantly, a previous meta-analytic review of stand-alone interventions to improve body image by Alleva and colleague (18) has provided evidence which cautioned against discussing physical activity with patients, as it was significantly associated with poorer body image outcomes. The meta-analysis proposed that by discussing physical activity as an intervention, patients may inadvertently have their attention drawn to their own weight and appearance, as well as the associated societal standards for physical fitness and physical attractiveness. Further, it was also not reported to be significantly associated with larger intervention effects on body image. Until the literature on the underlying mechanism between physical activity and body representation is further investigated, physical activity-related interventions targeting body image/representation should therefore be exclusively kept to psychologically healthy populations or be closely embedded in an overall treatment concept.

Notably, objective improvements in bodily composition and physical fitness brought about by PI are inconsistently related to changes in body image. This is surprising, insofar as people typically assume that their body image is based on an objective evaluation and comparison of their body. Instead, it appears that complex appraisal processes, eventually involving perceived improvements in physical capacities or more intense somatosensation experiences during PI may play a more important role. PI interventions could serve to improve body image/body representation by allowing individuals to redirect their attention more toward the functionality of their body and less on their appearance, or by increasing their sense of physical efficacy (69, 70). In this sense, the previous literature supports the need for a comprehensive, multisensory assessment of body representation as suggested by the Longo framework.

Strengths and Methodological Considerations

To our knowledge, this review is the first to provide a comprehensive systematic review on the topic of the longitudinal interactions between PI and body representation —the definition of which we have updated and adapted to fit the more complex theories and discussions which have arisen over the years.

Methodological limitations of this review arise from our study selection process as well as fromthe included studies. As we only searched for published results, a publication bias towardsignificant effects cannot be excluded. Further, as terminology in the field is very heterogeneous,it is possible that despite our broad search strategy, a few relevant articles may have been missed.Notably, some of the included studies had small sample sizes and may have been underpowered. Thecurrent systematic review is also potentially limited by biases within studies. Although nosystematic risk of bias across or within studies were identified, 97% of the included studies wereconsidered at risk with regards to selection bias and study design. More importantly, all studiesare lacking in the variety of validated outcome measures. Only self-report questionnaires wereimplemented, and the main component of body image addressed here was body satisfaction or the lackthereof. Additional visual scales implemented were used to measure the disparity between participants' subjective ideal versus actual body shapes, which, once again, only measured participants' attitudinal/conceptual issues of their own body image. Moreover, the two studies whose results also reported long-term effects of PI on body image were shown to be in direct contradiction (40, 50). One possible explanation for the contrasting results might be the difference in the type and dosage of the PIs implemented. As such, it remains unclear whether PI-induced body image improvement is indeed sustainable.

Perspectives and Future Directions

Our systematic review revealed that evidence on PI as a means to change body representation is still limited. A major challenge for future research is not only to reduce selection bias in the investigated samples, but also to explore potential mechanisms of body image improvement *via* PI through adopting a broader perspective on body representation. Based on our review, we argue for a more comprehensive view that takes various sources of information about the body into account (71, 72). In pursuit of a mechanism-oriented intervention, it is imperative to have a solid grasp on the understanding of how body image/body representation are constructed and which aspects drive changes in how individuals mentally represent their body.

The assessment of multisensory body representation is challenging. However, an increasing number of experimental paradigms have been developed in recent years to assess such concepts as: interoception [e.g., (73–75)], implicit knowledge of body dimensions (76–78) and multisensory integration (24). Despite reports of potentially disturbed multisensory integration and interoception in eating disorders (24, 79, 80), these measures have so far been largely neglected in clinical research. We expect that a broader use and further development of these methods in body representation assessment could give rise to a more informed understanding of the mechanisms of disturbed body representation and its malleability.

To this end, it is important to undertake future research on (i) identifying valid tasks to investigate different body representations (e.g., through combining actual body measures with tasks assessing body size estimation, interoceptive abilities or affordance estimates with questionnaires assessing cognitive-affective appraisal of the body), and (ii) investigate the malleability and interactions between different body representations.

AUTHOR CONTRIBUTIONS

DS, KG, SB, SZ, and AT conceptualized the project. DS, SB, and L-MW performed the literature review. DS wrote the first draft of the manuscript. SB, KG, HW, and AT critically reviewed the manuscript with respect to their areas of expertise: body image and eating disorders (KG, SB, SZ); philosophy and cognitive science of body perception (HW); and sports science (AT).

FUNDING

This review was supported by a grant from the intramural graduate school "iReAct" of the University and the University Hospital Tübingen. We acknowledge support by Open Access Publishing Fund of the University Tübingen.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

How does physical activity change body image?
Exploring the roles of interoception and affective response to physical activity in longitudinal body image outcomes

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Acknowledgements

This article was supported by a grant from the intramural graduate school "iReAct" of the University of Tübingen and the Medical University Hospital Tübingen. We would like to thank all participants for their time and commitment to the study; the iReAct team for their support in planning the multidisciplinary project and carrying out the extensive data collection; Prof. Dr. Sarah N. Garfinkel and Dr. Lisa Quadt for their collaboration, specifically for providing the scripts for the interoception tasks and support with the relevant equipments. The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Abstract

Among the positive effects of physical activity, body image improvement has been implied. However, there is a lack of investigations into how factors such as interoception and affective response to physical activity contribute to body image outcomes post physical activity intervention. The present study evaluates the extent to which different facets of affective response mediate the association between different aspects of interoception and body image outcomes after engagement in physical activity. Participants were 29 previously sedentary adults who successfully completed a 12-week physical activity intervention program. Affective valence assigned to the experience of physical activity was found to mediate the relation between individuals' perception of interoceptive cues and subsequent improvement in their body image, specifically—the health and physical efficacy-related perception of their body dynamics. Interestingly, individual differences in interoceptive accuracy and interoceptive awareness do not predict changes in body image. Our results suggest that effects of physical activity on body image are independent from individual differences in interoceptive abilities. Instead, body image improvement was achieved when positive valence was assigned to interoceptive cues experienced during exercise. Health-related practical implications of the current findings are discussed.

Keywords: Affective Response, Body Image, Body Representation, Interoception, Physical Activity

Introduction

Physical activity has been widely regarded by the public health sphere as a 'poly-pill'. It has been shown that regular engagement in physical activity can aid in the development, improvement, as well as maintenance of a variety of physiological as well as psychological aspects of individuals' health and well-being (Friedenreich & Cust, 2008; Hu et al., 2001; Sharma et al., 2006; Thompson et al., 2003; Wen et al., 2011; Wolin et al., 2009). As such, recommendations of regular physical activity as well as caution against avoidable sedentary behaviour have been commonly issued by healthcare professionals as well as public health organisations worldwide (e.g., World Health Organisation, 2018). However, sedentary behaviour is still increasing within the adult population, while engagement in aerobic activities stagnates (Du et al., 2019).

Physical activity training has been identified as one of the main interventions aimed at improving individuals' body image (Alleva et al., 2015). The term *body image* can roughly be defined as the conscious, mental representation of the body which integrates perceptual signals, cognitions, and affective attitudes toward the body (Gallagher, 2000; Longo & Haggard, 2010). However, within the sports and physical activity-related research fields, the term has often been conceptualised as bodily satisfaction—which refers to the cognitive-affective aspect of body image while excluding the rest. Any individuals, regardless of their current body weight and shape, are able to experience and suffer from negative body image, which has been shown to be associated with poor mental as well as physical health across genders (Gillen, 2015). Interestingly, previous literature have also indicated that, regardless of actual improvement in fitness level and body mass index (BMI), body image can be improved via participation in physical activity (Campbell & Hausenblas, 2009). More recently, Srismith and colleagues (2020) synthesised empirical findings from longitudinal intervention studies on effects of structured physical activity on body representation. Although the domains of visual, tactile and affordance perception of body representation were not investigated in any of the reviewed studies, the overall finding was consistent: the implementation of structured physical activity intervention (PI) was shown to be efficacious in increasing individuals' satisfaction with their own body. However, the reviewed studies neither explicitly proposed any form of a mechanistic interplay between physical activity and body image, nor provided evidence to support one. Additionally, the reviewed effects were found within samples of volunteered participants, which did not allow findings to be readily applicable to the average population.

Inter-individual differences in sensitivity to internal bodily sensations (i.e., *interoception*) have been associated with differences in body image. Distorted body image and altered interoceptive processing have also been identified as key characteristics of eating disorders—specifically anorexia and bulimia nervosa (see Badoud & Tsakiris, 2017 for a review). In particular, lower interoceptive accuracy (i.e., individual's performance on objective behavioural tests related to interoceptive cues) and awareness (i.e., individual's metacognitive awareness of their own interoceptive accuracy) are associated with body image concerns. Current literature also reported lower levels of interoceptive accuracy and awareness in relation to several stimuli (e.g., cardiac, hunger, physical pain, etc.) in patients with severe body image disturbances (e.g., Pollatos et al., 2008; Santel et al., 2006; Strigo et al., 2013). However, studies examining the correlations between interoception and body image in healthy populations are relatively sparse. Overall, a moderate inverse relationship between interoceptive accuracy and body dissatisfaction has been reported (Duschek et al., 2015; Emanuelsen et al., 2015; Holmes et al., 2015). Based on this line of evidence, though arising from cross-sectional and correlational studies, a hypothesis of a mechanistic relationship between interoception and body image in healthy individuals is appropriate.

Individuals' *affective response* during engagement in physical activity has been proposed to be a crucial factor to engagement as well as long term adherence to physical activity (Rhodes & Kates, 2015). Specifically, positive or negative affect induced by physical activity may contribute to the formation of a "memory trace" of the same valence for physical activity, which could subsequently have a significant influence on individuals' decisions to adhere to, or drop out from regular participation in physical activity (Ekkekakis et al., 2011; Ekkekakis & Petruzzello, 1999). As affective response is a close predictor of long term maintenance of physical activity, it may also be linked to individual differences in interoceptive abilities and, subsequently, body image—especially when considering the dual-mode theory (Ekkekakis, 2003; Ekkekakis & Acevedo, 2006). The theory describes the relative importance of cognitive and interoceptive influences on individuals' affective response to physical activity when exercising at different intensities. Despite the fact that interoceptive cues have been cited as one of the most salient determinants of affective response at higher intensities, there is a significant lack of studies in terms of the overall interaction between varying interoceptive abilities and affective response, and in turn, how affective response to exercise could have an affect on body image outcomes—especially in the context of inter-individual variability. This gap in knowledge is a significant barrier to future development and subsequent implementation of individualised counselling for appropriate PI based on individuals' aims and expectations.

In this study, the aim is to shed light on how such a mechanism might work. Specifically, the main questions are as follows:

1. which interoceptive dimensions (i.e., *interoceptive accuracy*, *interoceptive awareness*, *perception of interoceptive cue*s) might be relevant in the determination of body image outcomes;
2. which dimensions of body image (i.e., *negative evaluation of the body*, *perception of vitality/body dynamics*) is most affected by physical activity; and
3. which aspects of individuals' affective response (i.e., *perceived activation*, *affective valence*, *exercise enjoyment*, *exercise avoidance*) drives the effect of physical activity on body image outcomes.

To answer this, longitudinal data of 29 sedentary, medically healthy, adults who volunteered to take part in a 12-week PI program (the iReAct project; Thiel et al., 2020) is examined. Specifically, interoception, mediated through individuals' affective response to being physically active, is proposed to determine improvement in body image observed post PI. Extrapolating from the existing interoceptive literature, it is also expected that higher interoceptive accuracy and awareness, as well as a more positive evaluation of interoceptive cues, would be significantly associated with more positive body image outcomes.

In order to systematically explore the interrelationships between interoception, affective response to physical activity, and body image outcomes, all of which contains different aspects and facets to consider, three mediation models are proposed—each of which designed to examine such relationships from a different perspective.

Model 1: the *perception model* takes a bottom-up perspective, where interoceptive accuracy is hypothesised to predict improvements in perception of body dynamics, mediated by perceived activation rating during physical activity.

Model 2: the *cognition* model highlights the top-down perspective, where interoceptive awareness predicts resultant changes in negative evaluation of the body, mediated by individuals' affective valence rating during physical activity.

Model 3: the *valence* model emphasises the subjective experience of individuals, where individual differences in perception of interoceptive cues predict changes in the perception of body dynamics, mediated by affective valence rating during physical activity.

Physical activity-based interventions have been proposed to improve body image by encouraging individuals to focus more on the functionality of their body and less on their appearance, thereby increasing their sense of self-efficacy (Ginis & Bassett, 2011; Martin & Lichtenberger, 2002). As such, the perception of body dynamics dimension of body image was included as the outcome variable in models 1 and 3. Perceived activation is proposed to be the mediator in model 1, as per the hypothesis that individuals who are better at perceiving interoceptive cues (thereby scoring higher in interoceptive accuracy) may experience and report higher activation during physical activity, which could lead to subsequent changes in their perception of their own body dynamics. Interoceptive awareness is included as a predictor variable in model 2 in order to take into account individuals' metacognitive awareness of their own interoceptive accuracy. Additionally, there might be a relationship between interoceptive awareness and individuals' negative evaluation of their own bodies, as formation of both variables require elaborate thought processes (hence, a top-down perspective). Here, it is hypothesised that the relationship between interoceptive awareness and negative evaluation of body image is mediated by affective valence, as it encapsulates individuals' acute feelings and emotional states during physical activity—the rating of which could directly relate to the individuals' subsequent evaluation of their own body. Model 3 takes into account individuals' subjective evaluation of experienced interoceptive cues (i.e., whether they feel the experienced bodily signals are disturbing or beneficial), as well as their emotional states during physical activity; both of which are hypothesised to have an effect on subsequent changes in the perception of body dynamics as they might have direct bearing on changes in individuals' evaluation of their own physical efficacy. Due to the explorative nature of the current research, the three models proposed are considered to be mutually exclusive.

Method

Participants

Twenty-nine healthy participants (M_{age} = 27.07, SD = 5.62; 69% female) who took part in the iReAct project (Thiel et al., 2020) were examined in this study. The iReAct project is designed as an interdisciplinary research network investigating individual's physiological, affective, and cognitive responses to high intensity interval training (HIIT) versus moderate intensity continuous training (MICT). The study was approved by the ethics committee of the Medical University Hospital Tübingen, Germany (No.:882/2017BO1) and was registered at the German Clinical Trials Register (No.: DRKS00017446, available at https://www.drks.de).

Participants were provided with a detailed statement and explanation of what the study would entail. Informed consent was obtained at the point of recruitment. All participants reported insufficient engagement in physical activity at the time of recruitment (i.e., less than 150 min/week of physical activity; less than 60 min/week of physical activity during leisure time; no regular engagement in physical activity during the last 6 months; maximum oxygen uptake (VO_2max) between 25 and 50 ml/min/kg). Participants were also medically ensured to be in good health (e.g., no current or history of eating disorder, obesity, or neurological illness; BMI between 18,5 and 30,0 kg/m2; no history of drug use or alcohol abuse; not currently pregnant or in a breastfeeding period). For a more detailed report on the recruitment procedure, inclusion and exclusion criteria, please refer to the published study protocol by Thiel and colleagues (2020).

Materials and Procedure

Cardiac Interoception

Three distinct interoceptive dimensions were measured at baseline. Interoceptive accuracy and awareness were assessed together in a separate session. Perception of interoceptive cues was assessed during the baseline reference training session, which was carried out before participants began taking part in their assigned PI. For more details on the reference training session, please refer to the Reference Training section below.

Perception of interoceptive cues. Immediately after completion of the reference training session, participants were asked to indicate their perception of interoceptive cues. This questionnaire item was introduced with: “Please indicate below how the following aspects have influenced your overall well-being during the training.”

Using a smartphone (Google Nexus 5; LG, Seoul, South Korea), with the application “movisensXS” (movisens GmbH, Karlsruhe, Germany), participants were asked to complete the following statement: "My physical reactions and sensations were..." on a visual analogue scale (VAS) via a sliding controller. This is an in-house designed, non-validated, single-item questionnaire based on Rose and Parfitt’s (2010) procedures. Three values on the scale were assigned modifiers: 0 as ‘very disturbing’, 50 as ‘neutral’, and 100 as ‘very beneficial’. Participants were able to freely move the slider and submit their answer at any position on the scale.

Interoceptive accuracy and interoceptive awareness. Separate from the reference training session, participants were invited take part in another assessment for interoception. Two heartbeat detection measures determined interoceptive accuracy and awareness: heartbeat tracking task (Schandry, 1981) and heartbeat discrimination task (Brener & Kluvitse, 1988; Katkin et al., 1983; Whitehead et al., 1977). Both tasks were implemented in accordance to the experimental paradigm described in Garfinkel et al. (2015).

While comfortably seated on a chair, participants' heartbeats were monitored throughout the session via a pulse oximeter attached to their non-dominant index finger ('soft' mount PureLight sensor; Nonin Medical Inc., MN, USA). Participants were also instructed to rest both of their hands on the table in front of them, assuring no contact with any part of the body.

For the heartbeat tracking task, participants were instructed to "silently count the number of heartbeats you feel from the time you hear 'start' to when you hear 'stop'". Six trials of varying duration (i.e., 25, 30, 35, 40, 45, 50s) were implemented in a randomised order. The number of counted heartbeats was orally reported at the end of each trial, which was subsequently recorded by the experimenter. Participants were not given any feedback on their performance accuracy.

In order to prevent timing of the tones which could provide cues to participants' heart rate, the heartbeat discrimination task was carried out following the heartbeat tracking task. For the heartbeat discrimination task, participants completed 20 trials, wherein a series of 10 auditory tones, presented at 440Hz for the duration of 100ms, were delivered synchronously or asynchronously to the participants' heartbeat. Participants were instructed: "You will hear ten auditory tones. Please tell me if the tones are in sync or out of sync with your own heartbeat.*"* The trials were equally divided into 10 synchronous and 10 asynchronous conditions, the order of which was fully randomised for each participant. Participants responded immediately following each trial by stating whether the series of tones were either 'synchronous' or 'asynchronous' with their heartbeats. The answers were recorded by the experimenter before proceeding to the next trial. No feedback on participants' performance was given.

For both heartbeat detection tasks, immediately following each trial, participants were asked to give a confidence rating of their answer using a pencil on a 10 cm VAS, which ranged from 'total guess/no heartbeat awareness' to 'complete confidence/full perception of heartbeat'.

Affective Response to Physical Activity

Four facets of individuals' affective response to physical activity were measured at pre and post, as well as throughout the baseline reference training session: affective valence, perceived activation, exercise enjoyment, and exercise avoidance.

Perceived activation and affective valence. Using the same smartphone setup as the one used to assess perception of interoceptive cues, participants' in-situ affective responses to physical activity were measured according to the circumplex model (Russell, 1980). Affective valence and perceived activation were measured at 7 different timepoints throughout the entire reference training session: at minutes 0 (pre-training), 10, 20, 30, 40, 50, 60 (post-training). Data obtained immediately post-training (minute 60) were used in the analysis.

Perceived activation was assessed using the German translation of the Felt Arousal Scale (FAS; Maibach et al., 2020; Svebak & Murgatroyd, 1985), where participants were prompted to rate their current level of arousal on a 6-point scale, ranging from 1 'low arousal' to 6 'high arousal'. Affective valence was assessed using the German version of the Feeling Scale (FS; Hardy & Rejeski, 1989; Maibach et al., 2020), where participants were prompted to rate their current feelings on an 11-point bipolar scale ranging from: +5 'very good', through 0 'neutral', to -5 'very bad'.

Exercise enjoyment and aversion. The single-item Exercise Enjoyment Scale (EES; Stanley & Cumming, 2010) was adapted to assess participants' enjoyment immediately after completion of the reference training session. On the same smartphone set-up, participants used a VAS (with values ranging from 0 to 100) respond to the following item: "Indicate here how much you enjoyed the physical activity."

According to the EES, another single-item measure was created to determine participants' degree of avoidance. Participants used the same VAS to give their response to the following statement: "Indicate here how much you have experienced unpleasant experiences/feelings during the physical activity."

Body Image

Body image scores were assessed at both baseline and follow-up (i.e., before starting & upon completion of the intervention) using the German version of the Body Image Questionnaire (BIQ-20; Fragebogen zum Körperbild/FKB-20; Clement & Löwe, 1996; Löwe & Clement, 1996). For the present analysis, the change scores (the difference between pre and post-intervention scores) were used. The BIQ-20 comprises of 20 items and assesses body image on two independent sub-scales: Perception of Body Dynamics (BIQ-PBD) and Negative Evaluation of the Body (BIQ-NEB). Specifically, the BIQ-20 was selected to measure body image outcomes in this current study due to its two-dimensional score from the two sub-scales. An individual's attitude towards their own body (i.e., subjective evaluation of own appearance, feeling of bodily coherence, emotional well-being in the body; measured by BIQ-NEB), as well as their perception of their own bodily vitality (i.e., physical efficacy, perception of health, feelings of vitality, interests in bodily activities; measured by BIQ-PBD), can be taken into account separately—the latter of which is especially appropriate in the context of physical activity. Several studies have proven the questionnaire's validity, reliability, sensibility, as well as specificity (e.g., Junne et al., 2019; Lamadé et al., 2011; Teufel et al., 2012).

Reference Training

The total duration of the reference training session was 60 minutes. Participants performed continuous cycling exercise consisting of a 10-minute warm-up period at a power output corresponding to 90% of the first lactate threshold, followed by a 50-minute period of constant load corresponding to the midpoint between the first and the second lactate threshold.

Physical Activity Intervention

All participants successfully underwent a total of 12 weeks regular physical activity, consisting of an average of 3 weekly training sessions. Supervision was provided for all training sessions to ensure all participants' completion of the minimum of 30 (of the total 36) training sessions by the end of the intervention. Participants underwent 6 weeks of HIIT as well as 6 weeks of MICT in randomised order. The training order was counterbalanced across participants.

However, for the purposes of our current project, we are concerned with the general effects of PI on body image outcomes. As such, the group comparison between training types and order (i.e., MICT-HIIT versus HIIT-MICT) is not relevant for the current work.

For a detailed report on the training specifications and timeline, please refer to the published study protocol by Thiel and colleagues (2020).

Data Pre-Processing

Cardiac Interoception

For the heartbeat tracking task, interoceptive accuracy score was derived for each trial: $1 - (|n\text{beats}_{real} - n\text{beats}_{reported}|)/((n\text{beats}_{real} + n\text{beats}_{reported})/2)$. Resulting accuracy scores were averaged over the 6 trials, yielding an average accuracy score for each participant (Garfinkel et al., 2015; Hart et al., 2013). For the heartbeat discrimination task, interoceptive accuracy was calculated as the ratio of correct to incorrect synchronicity judgements (range: 0 to 1).

Interoceptive awareness score, reflecting metacognitive insight into participants' performance, was calculated for the heartbeat tracking task using the within-participant Pearson correlation, *r*, between interoceptive accuracy and confidence rating for each trial. Interoceptive awareness for heartbeat discrimination task was quantified using receiver operating characteristic (ROC) curve analysis (Green & Swets, 1966) of the extent to which confidence predicted accuracy. Specifically, of the trial-by-trial correspondence between accuracy (correct/incorrect synchronicity judgement) and confidence rating (Garfinkel et al., 2015).

Statistical Analysis

Statistical analyses were performed in IBM SPSS Statistics version 26. Bivariate associations between the model variables were analysed with Pearson correlations. Mediation analysis was performed according to the approach by Hayes (2017), utilising the PROCESS macro for SPSS version 3.4. Inference about the indirect effect was determined by bootstrapping, reporting 95% bootstrap confidence intervals. The number of bootstrap samples was set at 10,000. Effects of the mediation analysis are reported as unstandardised effects (*b*). If statistically possible and meaningful, combined interoception scores from different tasks were used as predictors.

Results

Sample Characteristics

Sample characteristics of participants at pre and post-PI are presented in Table 1. All interoceptive and affective response measures presented in Table 1 were measured at baseline. Body image outcomes are reported as change scores, which are derived from the differences between baseline and follow-up BIQ scores.

A paired samples *t*-test was conducted to determine the changes in participants' body image scores. BIQ-20 scores at pre-intervention (measured at baseline) was compared to BIQ-20 at post-intervention (measured at follow-up) for both sub-scales. There was a significant difference between baseline BIQ-PBD (M=25.17, SD=7.90) and follow-up scores (M=34.55, SD=5.09); $t(28)=-4.70$, $p=0.000$. There was also a significant difference between baseline BIQ-NEB (M=32.07, SD=5.47) and follow-up scores (M=22.10, SD=6.48); $t(28)=5.70$, $p=0.000$.

Correlations

Table 2 displays the correlations between the assessed variables. Interoceptive accuracy from heartbeat tracking task correlated significantly with perceived activation (r=0.44, p<0.05). Perception of interoceptive cues correlated significantly with affective valence (r=0.53, p<0.01), exercise enjoyment (r=0.73, p<0.01), as well as exercise avoidance (r=-0.56, p<0.01). Change scores of BIQ-PBD and BIQ-NEB are significantly inter-correlated (r=-0.87, p<0.01). Additionally, both sub-scales of BIQ-20 are significantly correlated to a number of affective response dimensions. BIQ-PBD change score is significantly correlated to affective valence (r=0.51, p<0.01). BIQ-NEB change score is significantly correlated to affective valence (r=-0.39, p<0.05) as well as exercise avoidance (r=0.37, p<0.05). Additionally, a correlation analysis was conducted for mean perceived activation and affective valence scores taken across the entire duration of the reference training session and found comparable correlations to the ones reported above (taken at post-training).

Overall, it seems that the accuracy and perceptive aspects of interoception are significantly linked to a number of affective response dimensions. However, there was no significant correlations between any interoceptive dimensions and body image outcomes. Meanwhile, all dimensions of interoception investigated here were not intercorrelated, and there was no intercorrelation between perceived activation and affective valence.

Table 1. *Sample characteristics of participants (n=29)*

	Mean	Standard Deviation	Range
Gender[1]	20♀ 9♂	—	—
Age (years)	27.07	±5.62	20–40
Interoceptive Accuracy (Heartbeat Tracking)	0.65	±0.19	0.09—0.95
Interoceptive Accuracy (Heartbeat Discrimination)	0.50	±0.15	0.10—0.75
Interoceptive Awareness (Heartbeat Tracking)	0.16	±0.5	-0.63—0.96
Interoceptive Awareness (Heartbeat Discrimination)	0.49	±0.13	0.25—0.72
Perception of Interoceptive Cues	56.66	±19.32	14.00—90.00
Perceived Activation	4.34	±1.4	1.00—6.00
Affective Valence	1.79	±2.19	-3.00—5.00
Exercise Enjoyment	57.66	±24	9.00–87.00
Exercise Avoidance	37.52	±25.87	0.00–82.00
BIQ-20 Perception of Body Dynamics change score*	9.38	±10.76	-15.00–30.00
BIQ-20 Negative Evaluation of the Body change score*,2	-10.00	±9.41	-29.00–8.00

Note. [1]The frequency of male (♂) and female (♀) subjects instead of the mean is reported; [2]Negative value indicates reduction in Negative Evaluation of the Body. *All assessments were taken at baseline except for BIQ-20 change scores, which report differences between BIQ-20 scores at baseline and follow-up.

Mediation Analysis

Perception Model

The mean values of interoceptive accuracy from both heartbeat tracking and discrimination tasks were used in this current model.

The total effects model for interoceptive accuracy predicting BIQ-PBD change score was not significant [$F(1,27)=1.08$, $p=0.31$, $R^2=0.04$]. The mediation model that included perceived activation as a mediator was also not significant, [$F(2,26)=0.59$, $p=0.56$, $R^2=0.04$].

Cognition Model

Interoceptive awareness scores from the heartbeat tracking and discrimination tasks were computed separately in this current model, as the the mean interoceptive awareness scores across both tasks do not fulfil the normality assumption of mediation analysis.

The total effects model for heartbeat tracking interoceptive awareness predicting BIQ-NEB change score was not significant [$F(1,27)=1.08$, $p=0.31$, $R^2=0.04$]. However, the mediation model that included affective valence as a mediator was overall significant with 24% of the variance in BIQ-NEB change score explained [$F(2,26)=4.06$, $p<0.05$, $R^2=0.24$]. Nevertheless, the indirect effect that depicts the influence of interoceptive awareness on BIQ-NEB change score mediated by affective valence was not significant [$b=0.10$, 95% BCa CI (-0.05, 0.29)]. Additionally, heartbeat tracking interoceptive awareness does not significantly predict BIQ-20 NEB change score with affective valence in the model [$b=-5.76$, $t(26)=-1.70$, $p=0.10$]. However, affective valence significantly predicts change BIQ-NEB [$b=-1.97$, $t(26)=-2.61$, $p<0.05$].

The total effects model for heartbeat discrimination interoceptive awareness predicting BIQ-NEB change score was not significant [$F(1,27)=0.01$, $p=0.94$, $R^2=0.00$]. The mediation model that included affective valence as a mediator was also

Table 2. *Correlations among interoceptive dimensions, affective response to physical activity dimensions, and body image outcomes*

	INT_HTAc	INT_HDAc	INT_HTAw	INT_HDAw	INT_PIC	AR_PA	AR_AV	AR_ENJ	AR_AVO	Change BIQ20_PBD	Change BIQ20_NEB
INT_HTAc	—	0.10	-0.16	0.10	-0.24	**0.44***	-0.05	-0.23	0.33	-0.13	0.23
INT_HDAc		—	-0.05	0.28	0.01	0.01	-0.07	0.07	-0.01	-0.16	0.08
INT_HTAw			—	0.19	-0.21	-0.10	-0.23	-0.16	-0.04	0.26	-0.20
INT_HDAw				—	-0.02	-0.08	-0.12	-0.22	0.13	-0.14	-0.02
INT_PIC					—	0.15	**0.53****	**0.73****	**-0.56****	0.11	-0.23
AR_PA						—	0.13	0.24	-0.09	0.00	-0.09
AR_AV							—	**0.44***	**-0.60****	**0.51****	**-0.39***
AR_ENJ								—	**-0.45***	0.09	-0.20
AR_AVO									—	-0.36	**0.37***
Change BIQ20_PBD										—	**-0.87****
Change BIQ20_NEB											—

Note. *p<0.05, **p<0.01, two-sided. All assessments were taken at baseline except for BIQ20 change scores, which report differences between BIQ20 scores at baseline and follow-up.

Abbreviations. INT_HTAc: Interoceptive Accuracy from Heartbeat Tracking task; INT_HDAc: Interoceptive Accuracy from Heartbeat Discrimination task; INT_HTAw: Interoceptive Awareness from Heartbeat Tracking task; INT_HDAw: Interoceptive Awareness from Heartbeat Discrimination task; INT_PIC: Perception of Interoceptive Cues score; AR_PA: Perceived Activation score; AR_AV: Affective Valence score; AR_ENJ: Exercise Enjoyment score; AR_AVO: Exercise Avoidance score; Change BIQ20_PBD: Perception of Body Dynamics change score; Change BIQ20_NEB: Negative Evaluation of the Body change score.

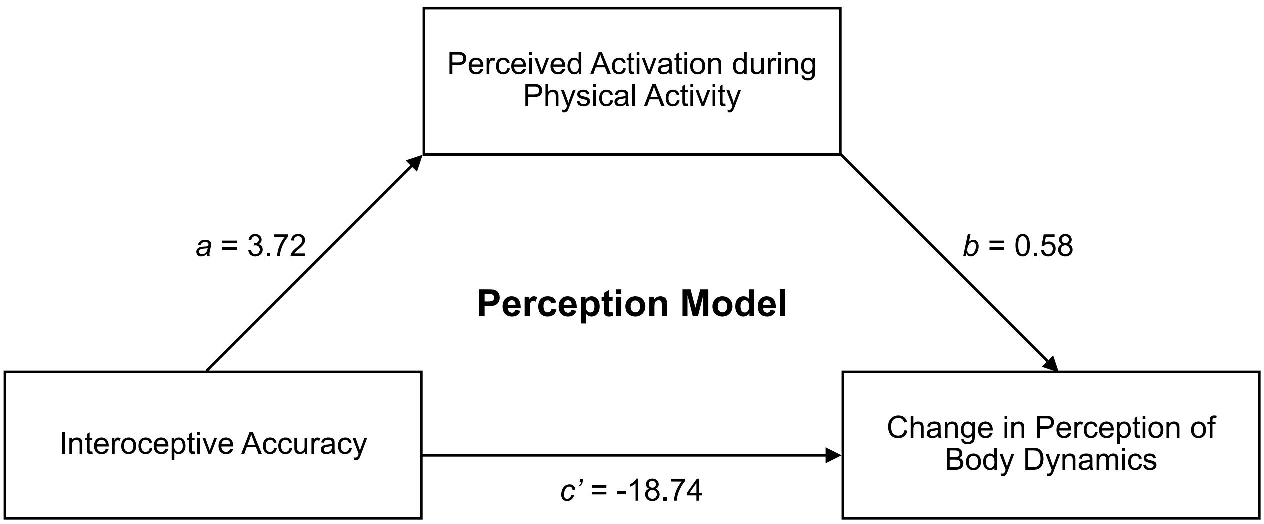
insignificant [$F(2,26)=2.41$, $p=0.11$, $R^2=0.16$].

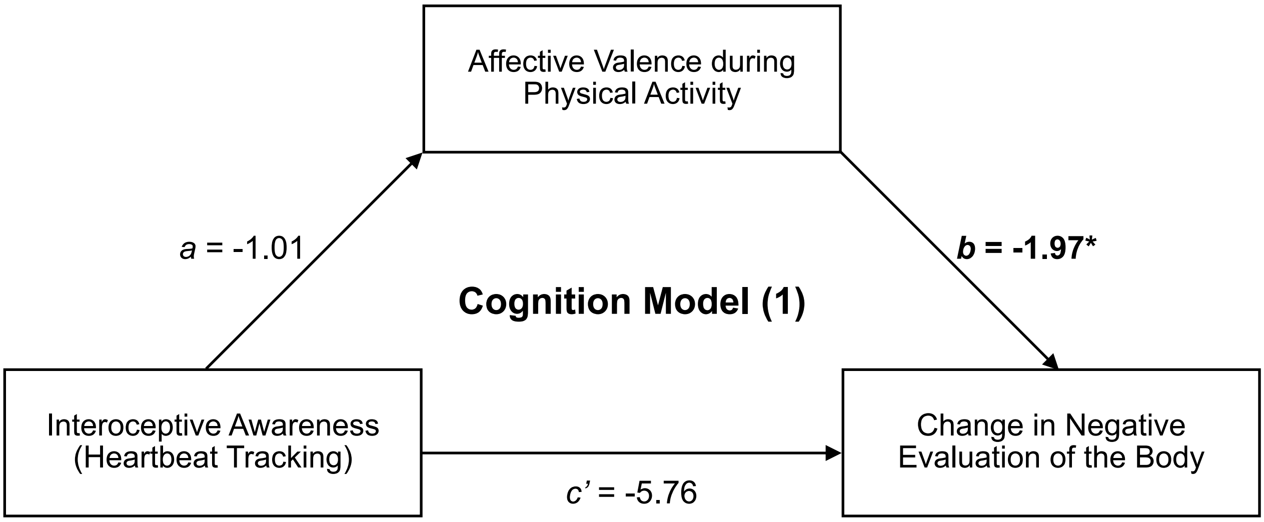
Valence Model

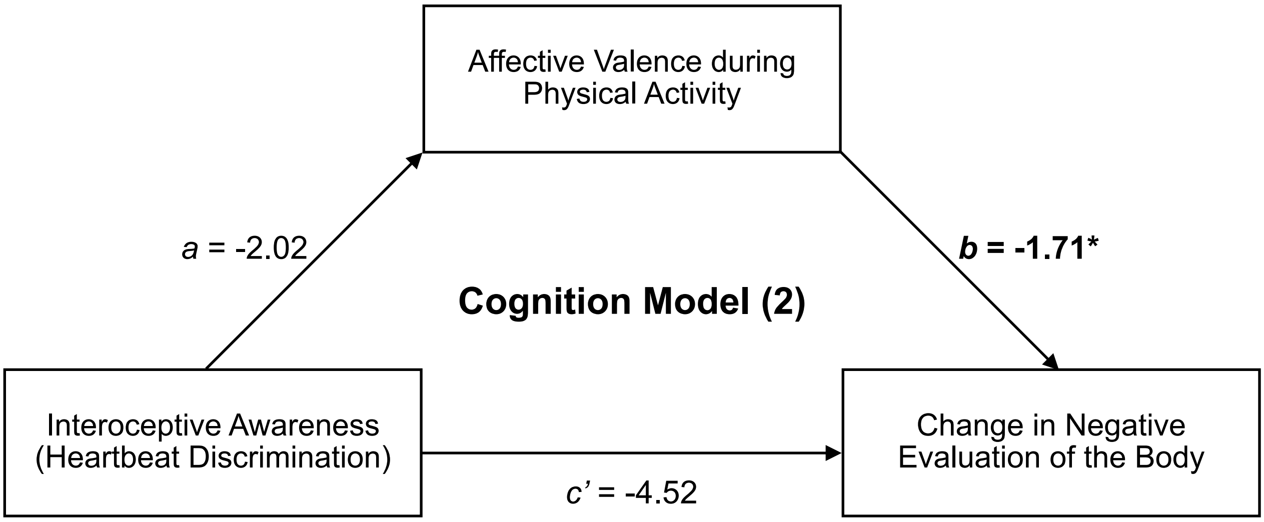
The total effects model for perception of interoceptive cues predicting BIQ-PBD change score was not significant [$F(1,27)=0.33$, $p=0.57$, $R^2=0.01$]. However, the regression of perception of interoceptive cues on the mediator, affective valence, was significant [$b=0.06$, $t(27)=3.2$, $p<0.05$]. Affective valence also significantly predicts BIQ-20 PBD change score, [$b=3.05$, $t(26)=3.2$, $p<0.01$].

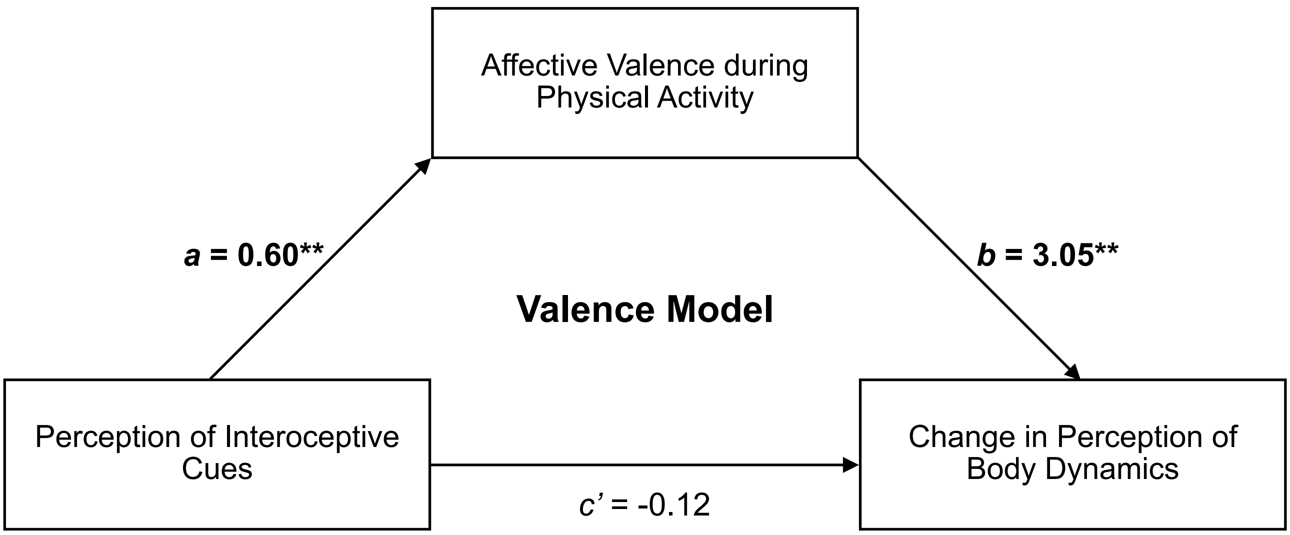
The mediation model that included affective valence as a mediator was overall significant [$F(2,26)=5.35$, $p<0.05$, $R^2=0.29$]. Additionally, the indirect effect that depicts the influence of perception of interoceptive cues on BIQ-PBD change score mediated by affective valence was significant [$b=0.33$, 95% BCa CI (0.07, 0.61)].

Figure 1. *Graphical illustrations of the mediation analyses on the proposed models concerning relationships between interoceptive dimensions, affective response to physical activity dimensions, and body image outcomes.*




Affective Valence during Physical Activity
a = -1.01
b = -1.97*
Cognition Model (1)
Interoceptive Awareness (Heartbeat Tracking)
Change in Negative Evaluation of the Body
c' = -5.76


Affective Valence during Physical Activity
a = -2.02
b = -1.71*
Cognition Model (2)
Interoceptive Awareness (Heartbeat Discrimination)
Change in Negative Evaluation of the Body
c' = -4.52


Affective Valence during Physical Activity
a = 0.60**
b = 3.05**
Valence Model
Perception of Interoceptive Cues
Change in Perception of Body Dynamics
c' = -0.12

Note. Displayed effects are direct effects. *p<0.05, **p<0.01, two-sided.

Discussion

Validation of theoretical models is important in elucidating potential factors contributing to the improvement of body image through participation in physical activity. Previous literature proposed that body image improvement through PI is mainly driven by shifting of the focus from bodily appearance to bodily functionality (Ginis & Bassett, 2011; Martin & Lichtenberger, 2002). Here, the data was able to verify that both perception of the body dynamics, as well as the subjective evaluation of the body, are significantly improved after long term engagement in physical activity. Not only did the current study confirm the fact that both facets of body image indeed significantly improved after regular engagement in physical activity, it also presented for the first time the interrelations and causality inferences between different aspects of individuals' interoception, affective response, and body image outcomes in the context of physical activity. Additionally, the current study is the first that tested different models describing the impact of distinct interoceptive and affective response dimensions on different aspects of body image outcomes. Here, an indirect relationship between individuals' perception of interoceptive cues and their perception of body dynamics was observed. Results suggest that the relationship between perception of interoceptive cues and perception of body dynamics is mediated by affective valence, and that affective valence in response to physical activity has a direct effect on individuals' perception of body dynamics.

Interestingly, both interoceptive accuracy and awareness measures neither correlated with, nor predicted, body image outcomes. Rather, in-situ assessment of individuals' perception of interoceptive cues proved to be a more valid measurement in this context. Unlike perception of interoceptive cues, measurements for interoceptive accuracy and awareness were taken while participants were in a state of calm, which contrast heavily with their state of (increasing) arousal when engaged in physical activity. This factor could render the measurements invalid for the purposes of predicting body image outcomes in the context of physical activity, thus emphasising the importance of in-situ assessment with regard to predicting outcomes related to physical activity. However, with respect to analysing the mediating role, this procedure could be seen as a limitation, as the mediator (affective valence) is assessed at the same time as the independent variable (perception of interoceptive cues).

Despite the aforementioned disconnect between objective interoceptive abilities and body image outcomes, significant correlations to dimensions of affective response exists in between. Interoceptive accuracy was shown to be significantly linked to perceived activation, while both aspects of body image outcomes are significantly linked to the affective valence. A closer look at the correlations also shows that the aversive component of affective response could be more relevant to body image outcomes, as compared to enjoyment. As such, it is still possible that (i) some other aspects of individuals' affective response not measured here might be responsible for mediating the link between interoceptive accuracy and body image outcomes, or (ii) a longer follow-up interval is needed to gain a clearer perspective. Intervention studies examining additional facets of affective response with a longer follow-up interval and more measurement time intervals could help to clarify these questions and help us learn more about the mechanisms through which body image outcomes is affected by interoception.

To overcome flaws of previous studies, three different potential mediation models were proposed and investigated, taking into account different aspects of all variables involved. The models highlighted both top-down and bottom-up aspects of cognition and perception (models 1 and 2) that might be at play, as well as take into account the more affective/subjective aspect of an individual's experience during physical activity (model 3). Results suggest that, while previous research has shown a definite link between interoception and body image and other aspects of body representation, individual differences in sensitivity to internal bodily sensations may not play such a large role in predicting body image outcomes in the context of physical activity. This could be due to the fact that individuals are always in a state of arousal during exercise. Individuals that are typically insensitive to their interoceptive signals while at rest simply cannot help but become aware of their internal bodily signals while being physically active, thus rendering such individual differences in interoceptive abilities obsolete. Additionally, the majority of studies detailing this link between interoception and body image only examined clinical populations; a different kind of interactions could be at play when considering the association between interoception and body image in healthy populations.

It is a limiting factor of this study that the sample size is relatively small. However, there are also several strengths to the study. The current study employed an interdisciplinary approach with a longitudinal design, in which participants were able to take part in a regular, rigorously supervised and well-defined PI. It also contributed to existing literature by examining interoception and body image outcomes in a sample of previously sedentary adults who recently committed to regular engagement in physical activity on a longitudinal basis. This is a highly relevant subset of the healthy population which has been insufficiently studied in research despite the growing global concerns of physical inactivity.

These observations suggest that, instead of focusing on individuals' degree of sensitivity to interoceptive signals and whether or not they are metaphysically aware of how 'good' they are at perceiving such signals, if the goal was to maximise their improvement in body image, individuals should place a larger emphasis on their affective valence while they're exercising instead. In other words, "find what feels good" seems to be an apt guideline based on the current findings. This is also in line with the current American College of Sports Medicine (ACSM) position statements and guidelines, which consider affective response as a secondary parameter of exercise prescription (Garber et al., 2011; Ladwig et al., 2017). However, it is important to keep in mind that this may be specifically relevant for those who have previously been sedentary and currently looking to improve their body image through physical activity.

Overall, the present study contributes to an improved understanding of body image outcomes in the context of longitudinal engagement in physical activity. Results suggest that effects of physical activity on body image are independent from both objectively measured interoceptive abilities as well as from perceived activation during physical activity. Instead, body image improvement was achieved when positive valence was assigned to interoceptive cues and experienced exertion. This, in combination with previous findings on the role of self-selection in physical activity, where self-paced physical activity elicited more positive affective response (although exercise intensity did not significantly differ between the self-selected and prescribed sessions; Hamlyn-Williams et al., 2014), highlights the importance of autonomy and self-paced exercise for affective responses, which could have a potential long term implications for both body image outcomes and physical activity adherence. Previous research also reported inter-individual variability in affective response to increase as a function of increased exercise intensity (Ekkekakis et al., 2011; Acevedo et al., 1994; Hardy & Rejeski, 1989; Parfitt et al., 1994). In other words, while some people may perceive heightened arousal as distressing, other people could very likely perceive the same intensity level as pleasant. This is especially relevant given the current findings. To combat the increasing sedentary behaviour observed in the adult population, future developments of interventions aimed to improve individuals' affective response to physical activity may be useful for increasing long term exercise adherence as well as improving body image. Further studies considering inter-individual affective response with regard to different physical activity intensity ranges (e.g., MICT & HIIT) would be also beneficial to this end.

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Comparative differences in body representation across physically active and sedentary adults

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Acknowledgements

This article was supported by a grant from the intramural graduate school “iReAct” of the University of Tübingen and the Medical University Hospital Tübingen. We would like to thank all participants for their time and commitment to the study; the iReAct team for their support in planning the multidisciplinary project and carrying out the extensive data collection; Prof. Dr. Sarah N. Garfinkel and Dr. Lisa Quadt for their collaboration, specifically for providing the scripts for the interoception tasks and support with the relevant equipments; Andrea Keller, Tsvetelina Alexiadis, Galina Henz, Didem Ergül, and Taylor McConnell for their help with the operation of the 4D scanner; Priyanka Patel and Haiwen Feng for their contributions in developing the technical setup for the body scan alignment process.

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Conflicts of Interests

In the last 6 years, MJB has received research gift funds from Intel, Nvidia, Facebook, and Amazon. He is a co-founder and investor in Meshcapade GmbH, which commercialises 3D body shape technology. While MJB is a part-time employee of Amazon, his research was performed solely at, and funded solely by, Max Planck Institute for Intelligent Systems.

Abstract

Body representation is vital for the creation and maintenance of the sense of self and identity that is unique to each individual. The goal of the current study was to provide a comprehensive assessment of body representation in healthy adult samples with high versus low physical activity. To this end, we complemented standard methods of cognitive-affective body image assessment with a novel body size perception task. We utilised realistic three-dimensional body models in combination with state of the art body scanning technologies, as well as provide measurements of cardiac interoception. We compared self-report data and experimentally derived parameters for body size perception, body image, and interoception between two samples of physically active (n=25, 60% female) and sedentary (n=47, 69% female) participants. Overall, active participants reported a more positive body image and better cardiac interoception, although metacognitive awareness related to interoceptive performance did not differ between groups. Analysis performed on Body Perception Index (BPI) derived from user-created body models of participants' perceived current and personal ideal bodies showed a significantly higher percentage of desired body change in sedentary adults. BPI and graphical comparisons between user-created self avatars and corresponding body scans did not show any perceptual deficits in body size perception in both groups. These findings, taken together with low levels of cognitive-affective body image and a significant self-ideal discrepancy observed in sedentary participants, suggests that such differences in body representation are not transient, and could indeed be due to long term adherence to routine physical activity.

Keywords: Body Representation, Body Image, Interoception, Interoceptive Accuracy, Interoceptive Awareness, Physical Activity, Sedentariness

Introduction

The health benefits of physical activity have been well documented. There is a substantial amount of literature emphasising the importance of an active lifestyle for individuals' optimal health and well being (e.g., Kwon et al., 2015; Shibata et al., 2015; Shook et al., 2015; Soares-Miranda et al., 2016). Specifically, regular engagement in physical activity has been identified as an effective preventive measure against numerous chronic medical conditions, as well as premature mortality (Warburton et al., 2006a; 2006b). In addition to increased quality of life and physiological well being, physical activity has also been associated with psychological health benefits (Edwards, 2006; Martinsen, 2009)—including an improved body image (Alleva et al., 2015; Campbell & Hausenblas, 2009; Srismith et al., 2020). Despite this, engagement in aerobic activities continues to stagnate within the adult population, while sedentary behaviour increases (Du et al., 2019). This is troubling, given the fact that, according to the World Health Organisation, sedentary behaviour reportedly accounts for approximately 9% of worldwide premature morbidity (Lee et al., 2012).

We theorise that body representation may be a key factor in explaining why some individuals experience barriers against participation in regular physical activity, while others are able to incorporate exercise into their daily routines. Body representation is a multi-dimensional concept. It integrates a conglomerate of mutually interacting body representations, which include the more explicit body image, as well as the processing of more unconscious, implicit bodily information. More recently, a framework by Longo (2016) proposed that different body-related representations can be categorised along the perceptual versus cognitive-affective, and implicit versus explicit, dimensions—which gives a clearer overview of the different representations underpinning the bodily experience. In other words, the concept of body representation encompasses basic awareness of the bodily status and dimensions, as well as how individuals may think, feel, perceive, and act with regard to their own body. We argue that a more comprehensive assessment of body representation is needed (beyond the frequently cited body satisfaction—i.e., cognitive-affective body image) when considering physical activity and its effects on an individual's relationship with their body—as the recruitment of internal bodily processes during exercise and its interplay with higher-order body-related percepts may provide an important clue into determining how physical activity affects how the body is represented overall. In order to elucidate how routine engagement in physical activity may affect how individuals represent their bodies as a whole, the current study compares body representation between sedentary and active participants by investigating the following aspects: *body size perception*, *body image*, and *interoception*.

Body size perception is defined here as a perceptual aspect of body representation, encompassing the conscious image of the size, shape, and physical composition of the body. Inaccurate body size perception has been associated with body image disturbances (Mölbert et al., 2017; Gaudio et al., 2014) as well as with motivation to engage in weight regulation behaviours (Assari & Lankarani, 2015). However, these findings have been identified as most likely due to instructions that made the task assess evaluations of body size rather than body size perception (Mölbert et al., 2017). In this study, body size perception is investigated with an emphasis on visual perception, so that potential biases in self-perception can be assessed, and to ensure validity of our computerised assessment of current-ideal body discrepancy.

In this study, body image refers to the explicit cognitive-affective representation of the body, which is comprised of subjective evaluations, beliefs, feelings and behaviours any individuals may have about their own body. Physical activity-based interventions have been advocated for and implemented across healthy and clinical populations with the aim of improving the cognitive-affective aspect of body image. Overall, such interventions have been shown to be efficacious (Alleva et al., 2015; Srismith et al., 2020). However, despite this generally positive association between body image and physical activity, we cannot overlook the well-documented observations that highly trained professional athletes are at an elevated risk of suffering from disordered eating and compromised body image (Bratland-Sanda & Sundgot-Borgen, 2013; Giel et al., 2016; Sundgot-Borgen & Torstveit, 2004). However, as there is no literature on the comprehensive characteristics of body representation in non-athletes, yet routinely active adults, it is still unclear whether there is such things as an 'optimum point', where the bidirectional relationship between physical activity and body image are mutually beneficial. Therefore, it remains to be seen if continuously active, non-athletes adults could benefit the most from physical activity in terms of body image.

Interoception, defined as the sense of the physiological condition of the body originating from the internal organs, is also investigated here in three different aspects in the context of cardiac activity: interoceptive accuracy, awareness, and sensitivity. Interoceptive accuracy refers to the performance on objective behavioural tests related to interoceptive cues (i.e., heart rate), while interoceptive awareness refers to the individual's metacognitive awareness of their own interoceptive accuracy. Interoceptive sensibility is conceptualised as individuals' self-evaluated assessment of their subjective interoception (i.e., the extent to which you believe you focus on and detect internal bodily sensations, Garfinkel et al., 2015). A bidirectional relationship between interoception and physical activity has been suggested, whereby interoception influences exercise performance and exercise performance induces changes in interoceptive processing (Craig, 2002; Schandry & Weitkunat, 1990). There is evidence that physical activity can affect interoception, although findings so far have been causally inconclusive (Borg & Linderholm, 1967; Georgiou et al., 2015; Montgomery et al., 1984).

In this study, we compared body size perception, body image, and interoception as three distinct representations under the broad definition of body representation between sedentary and physically active participants. To this end, we complement standard methods of cognitive-affective body image assessment with a novel visual body size perception and cognition task combined with custom three-dimensional (3D) body models, as well as provided measurements of cardiac interoception. Based on the existing literature, we hypothesised that both groups will perform accurately in visual body size estimation. However, we expected the sedentary group to report a less positive body image in self-report questionnaires and to display a larger discrepancy between their perceived current body and personal ideal body. The sedentary group is hypothesised to score significantly lower than their active counterparts in terms of their cardiac interoception measures.

Method

Participants

The current study is part of a larger PI-based study (the iReAct study; Thiel et al., 2020), where the initial power calculation performed for the overall study showed a projected sample of 60 participants to be sufficient for effect sizes of 74.9% to be shown. Here, 72 healthy native German participants (M_{age} = 25.5, SD = 5.17 ; 67% female) took part in this study; 47 of which were part of the sedentary group, while the remaining 25 were part of the physically active group. Sedentary participants were recruited from baseline assessments for the iReAct project (Thiel et al., 2020), designed as an interdisciplinary research network investigating individual's physiological, affective, and cognitive responses to high intensity interval training (HIIT) versus moderate intensity continuous training (MICT). Both active and sedentary participants were primarily recruited via the University of Tübingen and the Medical University Hospital Tübingen mailing list. All participants were provided with a detailed statement and explanation of what the study would entail. Informed consent was obtained at the point of recruitment. The study was approved by the ethics committee of the Medical University Hospital Tübingen, Germany (No.:882/2017BO1) and was registered at the German Clinical Trials Register (No.: DRKS00017446, available at https://www.drks.de).

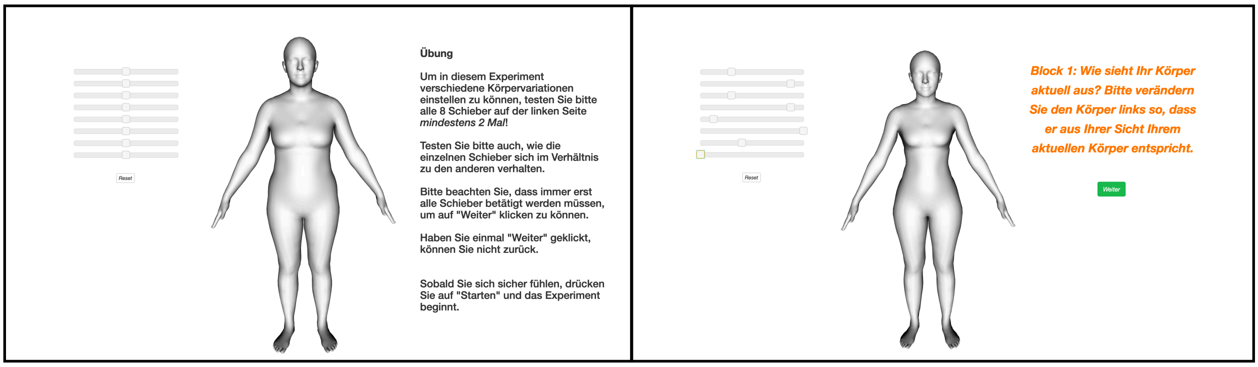
Eligible participants were medically ensured to be in good health (i.e., no current or history of eating disorder, obesity, or neurological illness; body mass index (BMI) between 18.5 and 30.0 kg/m^2; non-smoking; no history of drug use or alcohol abuse; not currently pregnant or in a breastfeeding period). All participants were asked to fill in a physical activity questionnaire (European Health Interview Survey–Physical Activity Questionnaire; EHIS-PAQ; Finger et al., 2015) in order to assess current physical activity levels. Participants who reported low engagement in physical activity at the time of recruitment (i.e., less than 150 min/week of physical activity; less than 60 min/week of physical activity during leisure time; no regular engagement in physical activity during the last 6 months) were included in the sedentary group. Participants who reported consistently high levels of engagement in physical activity at the time of recruitment (i.e., more than 150 min/week of physical activity; more than 60 min/week of physical activity during leisure time; regular engagement in physical activity during the last 6 months) were included in the physically active group. All recruited participants reported no participation in professional and/or competitive sports for the past 6 months.

Materials and Procedure

The assessment of body representation consisted of: an experimental session (1–2 hours), and a body scan session (30 minutes), which took place within 14 days following the experimental session. During the experimental session, participants were asked to complete three different tasks: (1) computerised body adjustment task (which measured body size perception and body image), (2) body image related self-report questionnaires, and (3) cardiac interoception tasks. As part of the iReAct study, sedentary participants underwent further assessments which are reported in Thiel and colleagues (2020).

Body Size Perception and Desired Body Change

At the beginning of the experimental session, each participant was informed that they will be completing a desktop-based task that involves creating “different versions of themselves using a 3D body model.” At the centre of the desktop screen, participants were presented with a manipulable 3D body model of an average person in a neutral pose at a frontal orientation, and were instructed to use the mouse to manipulate the 8 sliding scales on the left side of the screen in order to create desired changes to the body model. All sliders started in a neutral position. The texture of the body model was uniform grey, and gender of the body model corresponded to that of each participant. Participants were encouraged to take as long as they needed to familiarise themselves with the control sliders involved in the body model manipulation before proceeding to complete the actual task. Screenshots of the task are presented in Figure 1.



Controls Familiarisation Phrase

Body Adjustment Task & Example Instructions

Figure 1. *Illustration of the computerised body adjustment task. The task is available from the authors upon request.*

For this body adjustment task, the body shape visualisation tool by Streuber and colleagues (2016) was adapted. We used the geometric body space provided by the skinned multi-person linear (SMPL) model identity component (Loper et al. 2015) to generate a manipulable body model in a neutral pose for each gender. The generation of the manipulable body models was carried out in exact accordance with the details described in Streuber and colleagues (2016). The body models are represented by a 3D template mesh registered to high-resolution body scans obtained from the CAESAR dataset (Robinette et al. 2002), resulting in 1700 registered meshes for males and 2100 for females. In this study, the 8 sliding scales participants used to manipulate the average body model corresponded to the first 8 principal shape components from SMPL, which account for 96.56% of the identity-related body shape deformations in the shape training dataset.

After a test trial in which participants could familiarise themselves with the sliders and the way the body model could be transformed, participants were asked to adjust the average body model to create their own self-avatars according to four different instructions: (1) “what does your body currently look like?” (2) “what does your ideal body look like?” (3) “what does your ideal body look like from the perspective of your (potential) partner?” (4) “what does your ideal body look like from the perspective of a good friend?" Instruction (1) was designed to measure participants' body size estimation accuracy of their current body, while the remaining instructions were designed to measure their body image in terms of a potential discrepancy between their perceived current and ideal bodies. For the purposes of the current research, participant generated body models from instructions (1) and (2) were analysed, in order to keep the focus on individuals' perception of their own body and their own personal ideal—without the explicit influence of external social factors.

Each instruction was presented in a randomised order and repeated three times, resulting in four self-avatars created for each instruction, with the total of 16 self-avatars. In each trial, all sliders had to be moved before the participant could proceed to the next trial. The body model resets to the 'average' value (with all sliders location reset to the mean value) each time the participant proceeds to the next screen with a new instruction. The recorded output are the corresponding numerical values from the 8 principal components participants used to create their self-avatars. The experiment was not timed, and the participants were given as much time as they needed to create body models that correspond to what they had in mind.

3D Body Scan

The body scanning sessions took place at the Max Planck Institute for Intelligent Systems, Tübingen. We used a four-dimensional (4D) scanner which captures the full 3D human body shape at 60 frames per second (3dMD, Atlanta GA). The system is comprised of 22 pairs of stereo cameras, 22 colour cameras, and speckle-light projectors. The projected speckle patterns, alternating at 120 frames per second, allow accurate stereo reconstruction of 3D shape (https://ps.is.mpg.de/pages/4d-capture).

Participants were asked to take off all jewellery and change into standardised clothing provided by the institute for the body scan session. This consisted of grey underwear shorts, sports bra (if applicable), and a hairnet. Anthropomorphic data (e.g., height and weight) was collected before participants underwent the body scanning process. Participants were instructed to stand in the middle of the body scan in a neutral position, keeping their arms straight down at the side of their body and look forward as their body scan was being captured.

Body Image

To assess body image, a battery of self-report questionnaires was used: Body Image Questionnaire (BIQ-20; Clement & Löwe, 1996), selected sub-scales from Eating Disorder Inventory 2 (EDI-2; Garner et al., 1983; Thiel et al., 1970), Body Image Avoidance Questionnaire (BIAQ; Rosen et al., 1991; Legenbauer et al., 2007), and Physical Appearance Comparison Scale (PACS; Thompson et al., 1991; Mölbert et al., 2017). Further, the Rosenberg Self-Esteem Scale (R-SES; Rosenberg, 1989) was administered to assess a more global measure of self-esteem.

The R-SES contains 10 items which assess individuals' global self-esteem, with higher scores indicating lower self-esteem. The BIQ-20 consists of 20 items and assesses body image on two independent sub-scales: Perceived Body Dynamics (BIQ-PBD) and Negative Body Evaluation (BIQ-NEB). An individual's attitude towards their own body (i.e., subjective evaluation of own appearance, feeling of bodily coherence, emotional well-being in the body) is measured by BIQ-NEB, while their perception of their own personal vitality (i.e., physical efficacy, perception of health, feelings of vitality, interests in bodily activities) is measured by BIQ-PBD—the latter of which is especially appropriate in the context of physical activity. A higher score on the BIQ-NEB sub-scale indicates higher subjective bodily dissatisfaction, while a higher score on the BIQ-PBD sub-scale meant that individuals had higher subjective sense of physical efficacy. To examine body image related measures, two EDI-2 sub-scales were used in the current study: Drive for Thinness and Body Dissatisfaction, consisting of 16 items in total. The German version of the BIAQ is an 11-item questionnaire which measures different behavioural tendencies indicative of body image avoidance, where higher scores indicate greater body image avoidance. The PACS was implemented to assess individuals' tendency to compare their physical appearances in five different social situations. Participants who scored higher on the PACS indicate a strong tendency to compare one's appearance with others.

Additionally, the data obtained from the body adjustment task was also included as a measure of body image. As described above, we were able to graphically estimate participants' body dissatisfaction by looking if there were any distinct discrepancy between participants' perceived own body and their personal ideals. This is conceptualised as 'desired body change'.

Cardiac Interoception

Three distinct interoceptive dimensions were measured: interoceptive accuracy, interoceptive awareness, and interoceptive sensibility. Two heartbeat detection measures were used: heartbeat tracking task (Schandry, 1981) and heartbeat discrimination task (Brener & Kluvitse, 1988; Whitehead et al., 1977). Both tasks were implemented in accordance with the experimental paradigm described in Garfinkel et al. (2015).

While comfortably seated on a chair, participants' heartbeats were monitored throughout the session via a pulse oximeter ('soft' mount PureLight sensor; Nonin Medical Inc., MN, USA) attached to their index finger on their non-dominant hand. Participants were instructed to rest both of their hands on the table in front of them. No self-contact to any part of the participants' body was allowed in order to prevent pulse-checking or manual pulse-counting.

For the heartbeat tracking task, participants were instructed to "silently count the number of heartbeats you feel from the time you hear 'start' to when you hear 'stop'". Six trials of varying duration (i.e., 25, 30, 35, 40, 45, 50s) were implemented in a randomised order. The number of counted heartbeats was orally reported at the end of each trial. Participants were not given any feedback on their performance accuracy.

For the heartbeat discrimination task, participants completed 20 trials, wherein a series of 10 auditory tones, presented at 440 Hz for the duration of 100 ms, were delivered synchronously or asynchronously to the participants' heartbeat. Participants were instructed: "You will hear 10 auditory tones. Please tell me if the tones are in sync or out of sync with your own heartbeat." The trials were equally divided into 10 synchronous and 10 asynchronous conditions, the order of which was randomised for each participant. Participants responded immediately following each trial by stating whether the series of tones were either ‘synchronous’ or ‘asynchronous’ with their heartbeats. No feedback on participants’ performance was given by the experimenter before proceeding to the next trial.

For both heartbeat detection tasks, immediately following each trial, participants were asked to give a confidence rating of their answer on a 10 cm visual analogue scale, which ranged from ‘total guess/no heartbeat awareness’ to ‘complete confidence/full perception of heartbeat’.

Data Pre-Processing

Body Size Perception and Desired Body Change

To assess visual body size perception accuracy, the estimated current bodies from the adjustment task were quantitatively and graphically compared to scans of the actual body of the participant. In order to estimate BMI of the self-avatars generated by the participants, height and weight of the created body meshes were determined as follows: height (in meters) was determined by subtracting its ‘highest point’ with its ‘lowest point’; weight of the mesh (in kilograms) was obtained by first calculating the volume, in cubic meters, of the mesh as described by Zhang and Chen (2001) and dividing it by the average human body density (1010 kg/m^3; Satoh, 1992).

Accuracy of body size estimation was then determined through calculation of the Body Perception Index (BPI) according to the formula BPI = (estimated BMI/actual BMI) x 100 (Slade & Russell, 1973). Here, two measures of BPI were calculated: BPI for participants' perception of their (1) own body and (2) desired body change. For the calculation of own body BPI, estimated BMI is derived from participants’ estimation of their current body through the body adjustment task. This is computed against their actual BMI, which is derived from measurements of their height and weight. In order to provide a numerical measure for participants’ discrepancy between the perception of their own and personal ideal bodies, desired body change BPI was calculated using the following formula: (perceived current body BMI/personal ideal body BMI) x 100. Both values of BMI were derived from the visual body adjustment task. We subsequently ran one-sample *t*-tests of participants' own body BPI against the hypothetical accurate BPI of 100 for each group. An independent samples *t*-test was also computed to compare both BPI measures across the groups.

Graphical analysis of the differences between estimated and veridical bodies (i.e., adjusted self-avatar versus body shape data obtained from body scan) was done by creating differential illustrations of the estimated versus veridical bodies. To this end, body scans of the veridical bodies were aligned to a statistical model of body shape (SMPL, 2015; https://smpl.is.tue.mpg.de) which covers a wide range of shape, facial expression and pose space. For more technical details of the alignment process, please refer to (https://ps.is.mpg.de/publications/hirshberg-supmat-2012). Aligned body scans are parametrically comparable to the self-avatars participants created using the desktop-based paradigm since both were based on the SMPL body model. We then averaged estimated and veridical bodies across each gender in the two sub-samples to obtain average estimated versus veridical bodies. Lastly, we plotted differential figures between participants' veridical body and their estimation of their own body created via the desktop-based paradigm to obtain an overview of where the estimated versus veridical bodies differed.

Cardiac Interoception

Interoceptive accuracy score from the heartbeat detection task was derived for each trial: $1 - (|nbeats_{real} - nbeats_{reported}|)/((nbeats_{real} + nbeats_{reported})/2)$. Resulting accuracy scores were averaged over the 6 trials, yielding an average accuracy score for each participant (Garfinkel et al., 2015; Hart et al., 2013). For the heartbeat discrimination task, interoceptive accuracy was calculated as the ratio of correct to incorrect synchronicity judgements (range: 0 to 1).

Interoceptive awareness score was calculated for the heartbeat tracking task using the within-participant Pearson correlation, *r*, between interoceptive accuracy and confidence rating for each trial. Interoceptive awareness for the heartbeat discrimination task was quantified using receiver operating characteristic (ROC) curve analysis (Green & Swets, 1966) of the extent to which confidence predicted accuracy. Specifically, of the trial-by-trial correspondence between accuracy (correct/incorrect synchronicity judgement) and confidence rating (Garfinkel et al., 2015).

Lastly, interoceptive sensibility was derived from the mean confidence rating across both heartbeat discrimination and heartbeat tracking tasks. This produced a global measure of mean confidence for each participant.

Statistical Analysis

Statistical analyses were performed in IBM SPSS Statistics 27.0. Independent samples *t*-tests were calculated to examine group differences in sample characteristics, body size perception, body image, and cardiac interoception measures. The alpha was set at 0.05 for all analyses. Effect sizes were calculated with Cohen's delta.

Results

Sample Characteristics

Table 1 provides an overview on the sample characteristics. The groups did not differ in BMI, but sedentary participants were significantly older. Female participants were 60% and 69% of the active and sedentary groups, respectively.

Table 1. *Means and standard deviations for sample characteristics, as well as body image, body size perception, and interoception measures. Group differences were tested for significance with independent samples t-tests.*

	Active Group (n=25)		**Sedentary Group (n=47)**		**Sig. (*p*)**	**Effect Size (Cohen's *d*)**
	M	**SD**	**M**	**SD**		
Sample Characteristics						
Age	22.44	2.18	27.13	5.57	0.00	1.00
BMI (kg/m^2)*1	22.42	1.90	23.52	2.35	0.10	0.49
Body Size Perception						
BPI own body*1	93.06%	11.53	100.73%	10.91	0.02	0.69
Body Image and Self-Esteem						
BPI desired body change	-4.21%	7.09	-12.72%	10.98	0.00	0.87
R-SES	6.92	4.26	9.97	6.35	0.03	0.53
BIQ-20 Perceived Body Dynamics	39.12	4.30	32.70	5.46	0.00	1.26
BIQ-20 Negative Body Evaluation	19.60	5.65	24.31	7.66	0.01	0.67
PACS	14.04	3.53	14.87	3.66	0.36	0.23
BIAQ	6.52	3.94	7.15	5.18	0.60	0.13
EDI2 Drive for Thinness	16.32	7.78	17.83	7.38	0.42	0.20
EDI2 Body Dissatisfaction	22.28	10.15	29.36	8.89	0.00	0.76

Cardiac Interoception[*2]						
Accuracy	0.67	0.15	0.56	0.13	0.01	0.76
Awareness	0.29	0.30	0.32	0.27	0.69	0.11
Sensibility	6.17	1.76	4.33	1.83	0.00	1.03

Note. [*1]Due to missing data, BMI and BPI own body measures were derived from n=16 active participants.

[*2]Due to missing data, interoceptive measures were derived from n=31 sedentary participants.

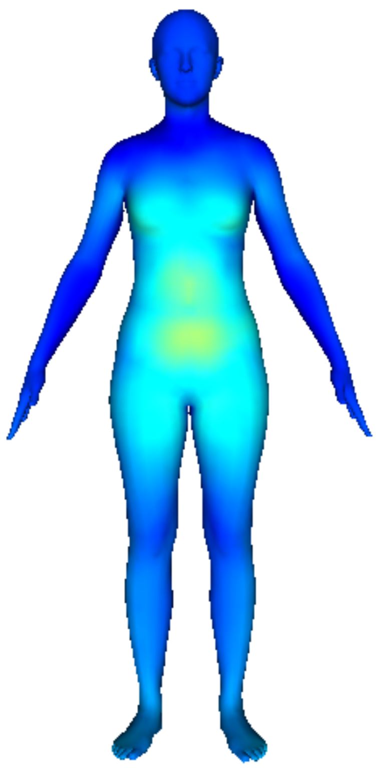
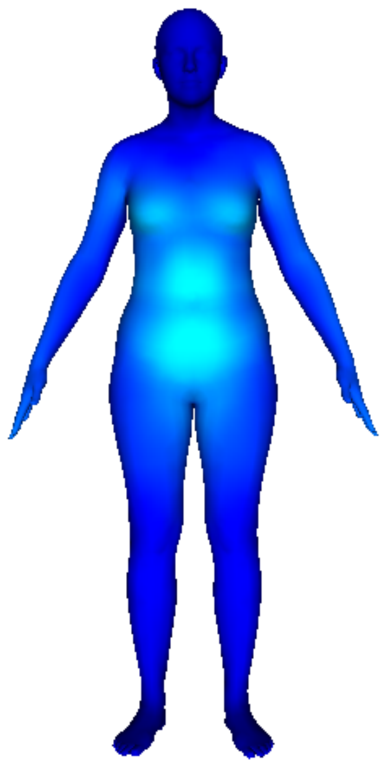
Abbreviations. BPI: Body Perception Index; R-SES: Rosenberg Self-Esteem Scale; BIQ-20: Body Image Questionnaire; PACS: Physical Appearance Comparison Scale; BIAQ: Body Image Avoidance Questionnaire; EDI-2: Eating Disorder Examination 2.

Body Size Perception

As reported in Table 1, BPI of participants' own body, computed from comparing participants' actual BMI and estimated BMI from adjusted self-avatars, differed significantly between groups, which suggests that active participants tended to underestimate their BMI when carrying out the body size estimation task. Analysis of own body BPI against the hypothetical accurate value of 100 using one sample *t*-test revealed that active participants estimated their 'current' body with a significantly lower BMI than their actual body ($t(15)=2.41$, $p=0.029$, $d=0.60$). Sedentary participants were comparatively more accurate than the active cohort in estimating their own body size ($t(43)=0.45$, $p=0.66$, $d=0.07$).

To check for potential deficits in body size perception, as well as general task adherence and data plausibility, we plotted the generated self-avatar for participants' perceived current body against veridical body (i.e., aligned body scans) for each group and inspected shape differences visually. Figure 2 shows body shape discrepancies between perceived current bodies and corresponding veridical bodies for each group, separated by gender. The colour coding spectrum reflects differences in body shape;

this ranges from dark blue (no shape discrepancy) to dark red (largest shape discrepancy). The shape discrepancy observed in the torso area for the active male participants is due to the presence of pronounced abdominal muscles in their corresponding body scans, which participants could not replicate using our body model adjustment task. Otherwise, shape differences occurred only in the context of height differences (this is depicted as colouration around the areas of legs and feet), which were irrelevant for the study questions. Overall, participants' estimations of what they perceive their bodies to currently look like seems to be accurate, as there is almost no discrepancy between generated self-avatars and their veridical bodies. This suggests that the tool was adequate to assess a variety of different body shape visualisations and that participants were able to generate meaningful bodies using our body adjustment tool.

Active Group (n=16)	**Sedentary Group (n=47)**
	

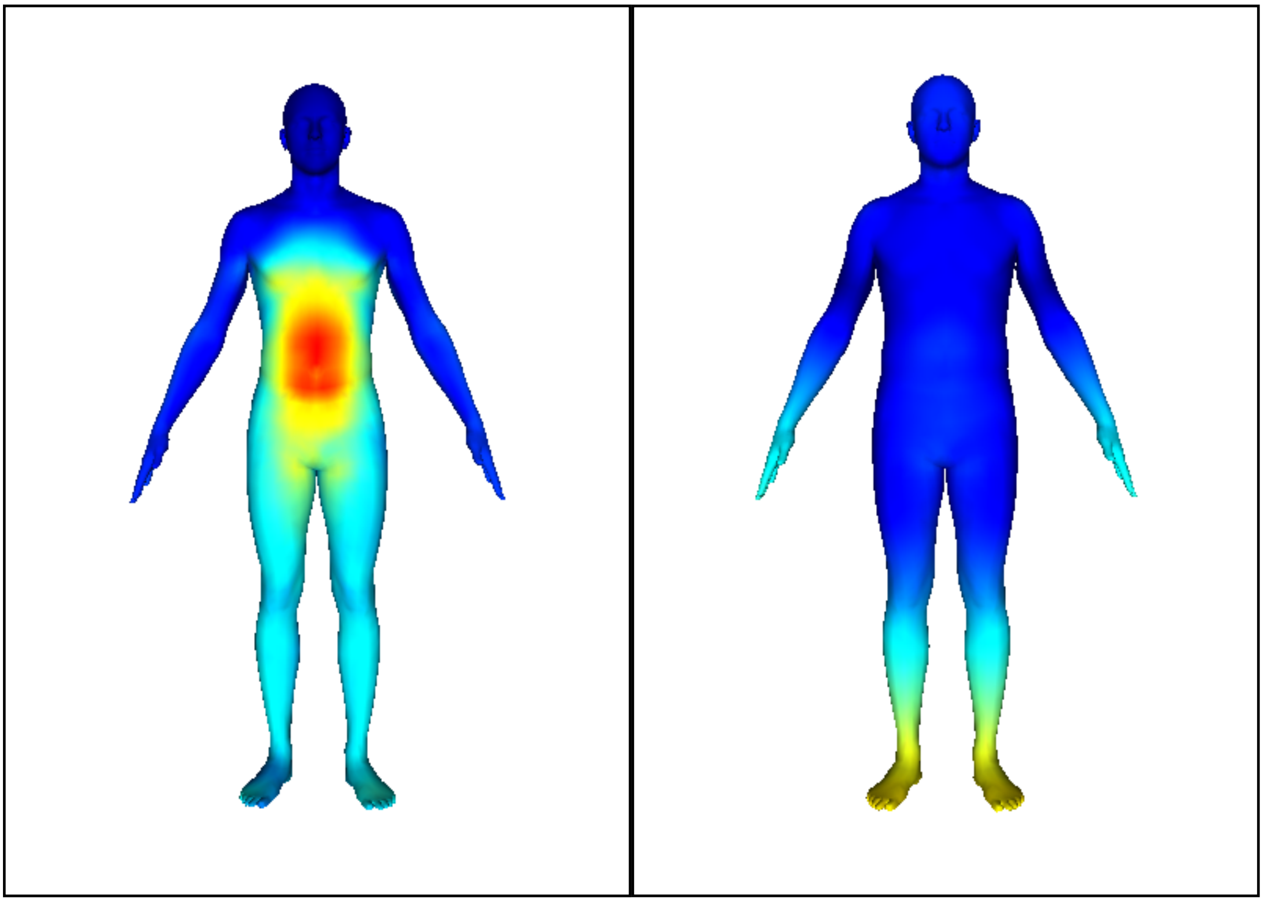


Figure 2. *Average body shape discrepancies between generated self-avatars for participants' current bodies and corresponding aligned body scans for each group, separated by gender. The colour coding on the bodies represent degrees of discrepancy between the body scans and the generated self avatars, with dark blue indicating no difference and dark red indicating the largest differences.*

Body Image

As presented in Table 1, the sedentary group reported less positive body image. As expected, Perceived Body Dynamics and Negative Body Evaluation from the BIQ-20 differed significantly between active and sedentary participants with marked effect sizes (d=1.26, d=0.67, respectively). Notably, while active participants reported much lower levels of Body Dissatisfaction (d=0.76) from the EDI scale, Drive For Thinness did not differ between the two groups. BIAQ and PACS scores also did not differ between groups. Overall self-esteem differed significantly between the two groups, as measured by R-SES. However, both groups reported very low levels of self-esteem when inspected against the traditional cutoffs (i.e., scores below 15 suggest low self-esteem).

BPI of participants' desired body change also differed significantly between groups (*d*=0.87), with sedentary participants adjusting for ideal bodies with significantly lower BMI than their perceived current bodies. Additionally, we plotted differential figures to visually inspect this current-ideal discrepancy. Using the same colour coded discrepancy spectrum, Figure 3 shows body shape discrepancies between generated self-avatars for participants' current bodies and their personal ideals for each group, separated by gender. While active participants observed almost no differences between their perceived current bodies and their personal ideal bodies, sedentary participants, on the other hand, created quite different self-avatars, the discrepancies between which were most pronounced in the torso and thigh areas. These visual differences mirror the reported BPI of participants' desired body change.

Active Group (n=25)	**Sedentary Group (n=47)**
	

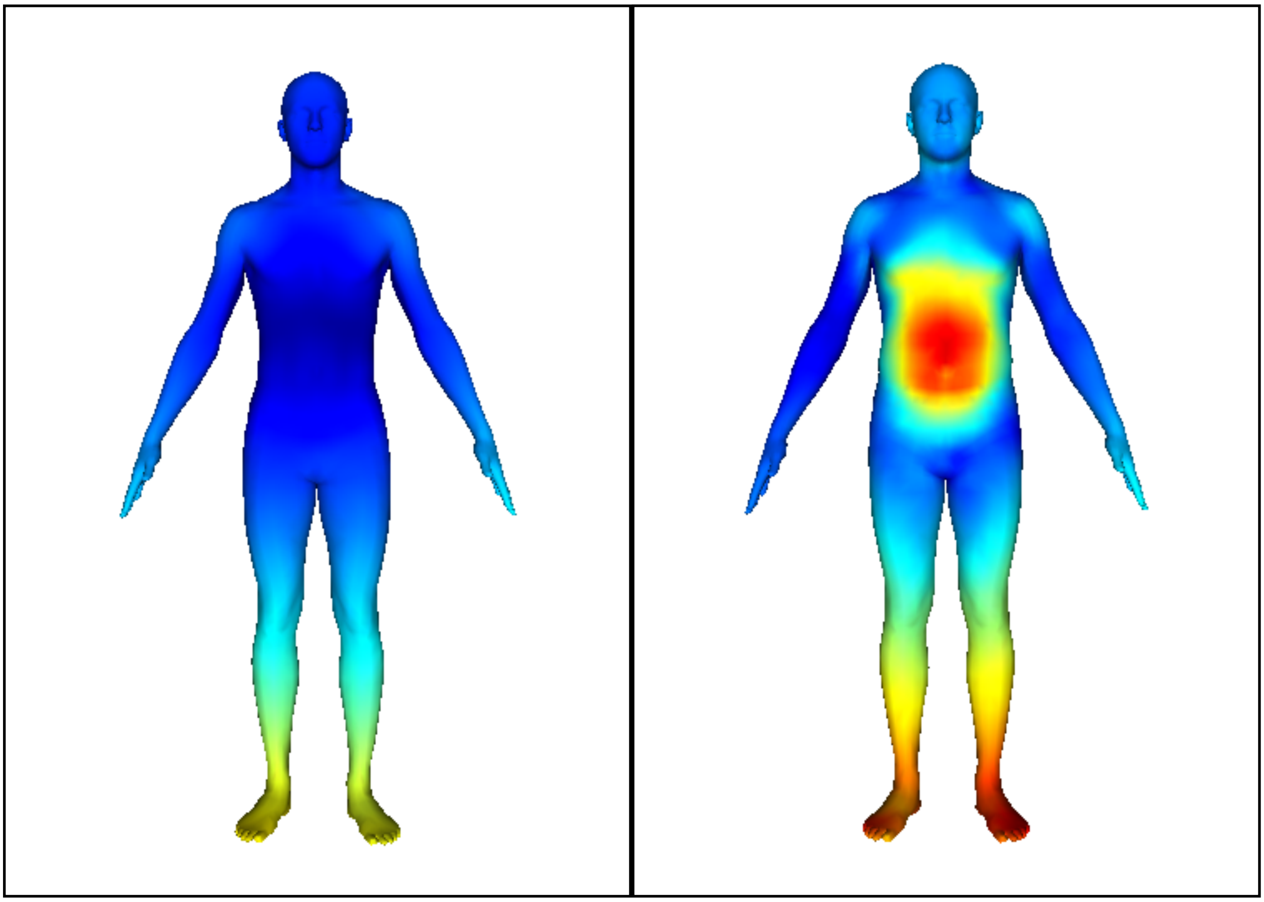


Figure 3. *Average body shape discrepancies between two versions of generated self-avatars, current versus personal ideal bodies, for each group, separated by gender. While the active group observed almost no differences between their current and ideal self-avatars, self-avatars created by sedentary participants of both genders differed quite distinctly in regions of interest, such as the torso and thighs.*

Cardiac Interoception

As for interoceptive measures, interoceptive accuracy and sensitivity differed significantly between groups (*d*=0.76, *d*=1.03, respectively). This suggests that, not only did active participants objectively perform better than sedentary participants in terms of cardiac interoception tasks, they also subjectively felt much more confident in detecting their internal sensations (in this case, their heart beats). Interestingly, despite this large difference in subjective interoceptive sensibility, participants' metacognitive awareness of their performance did not differ significantly. In other words, despite a much higher overall confidence in their interoceptive abilities, active participants could not accurately predict whether they were objectively good or bad at detecting their cardiac interoceptive signals.

Discussion

In this study, we provide a comprehensive assessment of body representation in sedentary and physically active adults. In addition to established methods of body image assessment, we implemented a novel computerised paradigm which allowed participants to work with modifiable, realistic bodies. This enabled us to visualise and analyse participants' perception and cognition in relation to their own bodies and addressed different aspects of body representation at the same time. This, in combination with state of the art body scanning technology, also enabled us to examine participants' body size perception in a way that has not been done before. Our observations suggest that, despite both of our cohorts being part of the healthy population, adults who have been sedentary for at least 6 months generally represent their body differently from their physically active counterparts. Overall, active participants showed more positive levels of cognitive-affective body image from both experimental visualisation and questionnaire-based findings. They performed significantly better in cardiac interoceptive tasks and reported higher levels of confidence in their interoceptive abilities. In sum, our observations suggest that regular physical activity induces long term positive effects on various facets of body representation.

Overall, the desktop-based body adjustment task is impressively valid. Participants were able to quickly familiarise themselves with the task and recreate their perceived body size and shape very well, as demonstrated by the overall lack of graphical body shape discrepancy between the self avatar and the veridical body obtained from the body scan. This paradigm could be used for further studies on body size perception and body image, even in the absence of the body scanner, as the estimated self avatar has been shown to be quite accurate across participants. However, BMI estimation can be problematic when considering populations whose body compositions lie outside the norm. While BMI is a generally good measure of adiposity/obesity for the general population, it cannot differentiate between adipose and muscle tissues. As muscle tissues are denser than adipose tissues (1.1g/ml and 0.9g/ml, respectively), individuals with higher muscle mass tend to have higher BMI despite being very lean. As such, while active participants could be very accurate at visually estimating their body size, the calculated estimation of BMI from SMPL models relies on the average human body density (1010 kg/m^3; Satoh, 1992), which could be problematic for a very lean cohort. The same problem could also arise in the case of obese individuals. In this study, we have controlled for participants' BMI range (between 18.5 and 30.0 kg/m^2), and although BMI did not differ significantly between groups, this still does not take into account individuals' body composition which could very well differ from the average population. This potential distortion could be reflected in their BPI measure and, consequently, this observed BMI underestimation. As such, it cannot be firmly concluded that visual body size perception deficit was observed in the active group. With emphasis on experimental methodology involving plausible modifications of naturalistic human bodies, we believe that the introduction of this methodological approach opens up new and more innovative venues to assess body-related perceptions, potential deficits and ideals in both healthy and clinical populations.

In line with our hypothesis, sedentary participants reported a less positive body image in self-report questionnaires. Despite this, Drive For Thinness, Body Image Avoidance, and Physical Appearance Comparison were observed in both groups. As these are behaviour related measures, we propose that it is likely that the more positive image observed in active participants is due to their routine engagement in physical activity, and less likely due to other body related habits, or the absence of external societal pressure and the subsequent internalisation of the thin/athletic body ideals. Notably, the sedentary group scored significantly higher in terms of global self-esteem. This is surprising, insofar as body dissatisfaction was observed as well as marked discrepancy between perceived current and ideal body. However, it should be noted that according to traditional cutoffs (Rosenberg, 1989), both cohorts scored quite low in global self-esteem.

In terms of cardiac interoception measures, sedentary participants performed significantly worse in both tasks. However, despite the differences observed in interoceptive accuracy and subjective confidence, differences in participants' metacognitive awareness of their interoceptive performance remained nonsignificant. In line with previous studies (Borg & Linderholm, 1967; Georgiou et al., 2015; Montgomery et al., 1984), our results imply that regular engagement in physical activity (and therefore regular exposure to interoceptive signals when in a state of arousal) may have an influence on interoceptive processes and associated subjective confidence. However, no causal conclusions can be drawn from our current results, as such observations can still be due to individual differences.

It is a limiting factor of this study that the sample size is relatively small and that both groups were not age-matched. However, there are also several strengths to the study. The current study employed multi-faceted paradigms and incorporated diverse tasks to comprehensively assess different facets of body representation. It also contributes to existing literature by filling in the research gap on the body representation characteristics of participant groups that are conceptually close to populations that experience distortions in body representation: eating disorder patients and elite athletes. We argue that our sample groups of non-athletes physically active adults and sedentary individuals are both highly relevant subsets of the healthy population that has been insufficiently studied in research. Another limitation of the study stem from technical and study design details. In this study, we presented average body shapes with grey shaded textures—i.e., no identifying characteristics or specific identities were provided via body model textures. Previous studies have highlighted the importance of texture characteristics which were proposed to modulate how much participants were able to identify with the stimulus and the mindset with which they completed the tasks (Mölbert et al., 2018; Thaler et al., 2018). Further, as mentioned above, the body adjustment task results may be biased due to the limited modification options available to the participants. Specifically, the SMPL body model (Loper et al., 2015) used for stimuli generation, and the body space in which degrees of body shape modification possibilities were confined, was created based on data from normal weight and overweight bodies. As such, individualised characteristics could very well be lost in the process of self-avatar creation as the body modification space does not cater for such factors as leanness or muscularity.

In conclusion, adults who engage in regular physical activity indeed represent their bodies differently than those who lead a more sedentary lifestyle. Specifically, active individuals possess a more positive body image and better cardiac interoception. These findings, taken together with low levels of self-report body image and a significant self-ideal discrepancy observed in sedentary adults, implies that such differences in body representation across the two groups are not caused by a transient effect arising from PI, and could indeed be due to long term and regular adherence to routine physical activity. Given the current findings, we propose that continuously active, non-athletes adults are highly likely to be the group that benefit the most from physical activity in terms of body representation. Taking into account the lack of studies in this field, our findings demonstrate the first evidence regarding the correlations between levels of physical activity and body representation in healthy populations. In order to further elucidate the role of body representation in exercise practice, future research examining a larger sample size is needed to shed light on the processes by which physical activity interacts with different aspects of body representation in a longitudinal setting, as well as elucidate the specific roles of BMI and other markers of physical fitness (e.g., VO_2max) in the improvement and maintenance of positive body representation.

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Acknowledgements

Thanks

I would like to express my gratitude to the following groups of people whose presence (online and offline) and support have helped make this dissertation project possible. My incredible supervisors: Simone Behrens and Katrin Giel. The iReAct supervisors and colleagues: Ansgar Thiel, Gorden Sudeck, Stephan Zipfel, Barbara Munz, Andreas Nieß, Hannes Gropper, Katja Dierkes, Felipe Maturana and Manuel Widmann. Hong Yu Wong and all colleagues from the Philosophy of Neuroscience group at the Centre for Integrative Neuroscience. All colleagues, administrative personnel and technicians from the Department of Psychosomatic Medicine and Psychotherapy at the Medical University Hospital Tübingen. Michael Black and all colleagues, administrative personnel and technicians from the Department Perceiving Systems at the Max Planck Institute for Intelligent Systems. The Ministry of Research, Science, and the Arts of Baden-Württemberg. The International Max Planck Research School for Cognitive and Systems Neuroscience/The Graduate Training Center of Neuroscience of the University of Tübingen and the Max Planck Society. My mother and sister: Butsaba and Sirikamol Srismith, for their abiding love and support from continents away. My friends across the time zones and the Lé sigh group for keeping my spirits up through these strange times. And finally: Albert, for always being there.