Utrecht University

Artificial Intelligence Master's thesis

# As feminine as you walk to be?
# Investigating Gender Identity and Social Cognition with Bodily Illusions

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Abstract

Body swap illusions, for example when embodying an avatar of a racial outgroup in Virtual Reality, have been shown to affect implicit attitudes towards the embodied group. This effect is theorized to occur through a change in the perception of one's *own* body, one's self-concept, and social cognition. Bodily illusions can also change the perception of one's own body. For example, altering footstep sounds can change one's perceived body weight and self-reported feelings of masculinity and femininity. However, the effect of illusions of one's own body on the self-concept and social cognition has not yet been explored. Such consideration is necessary to improve our theoretical understanding of the connection between body perception and social cognition. Therefore, I conduct two experiments. In the first experiment involving 26 cisgender females, I investigated the effect of real-time alteration of footstep sounds on perceived masculinity and femininity, self-gender association, and the relation to gender groups. Participants reported feeling more feminine and lighter, and perceiving themselves to be closer to the group of women directly after walking with feminine sounding footsteps. In a second experiment involving 26 cisgender males, men also reported feeling more feminine after walking with feminine sounding footsteps and associated themselves relatively stronger with the category 'female' in an Implicit Association Task. These findings provide evidence for the potential of footstep sounds to temporarily alter gender identity and for a connection between bodily experiences and the self-concept.

**Keywords:** bodily illusions; gender identity; self-concept; social cognition; auditory feedback; IAT

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# List of Tables

# List of Figures

# Content

# 1 Introduction

In her novel 'To Kill a Mockingbird', Harper Lee wrote, "*You never really understand a person until you consider things from his point of view… Until you climb into his skin and walk around in it*". The ability to change into the perspective of an individual and to empathise with them is a crucial element of mutual understanding and constructing social relationships. If an individual belongs to our ingroup, we display stronger empathetic responses towards them compared to an individual in our outgroup [86]. The identification with an ingroup often results in favourable attitudes towards this ingroup and in negative evaluation of outgroups [29, 85]. How close one feels to social in- and outgroups is considered to be related to prejudice and discrimination [21, 36]. Changing our relationship to our in- and outgroups could therefore influence our attitudes towards these groups and provide an opportunity to address prejudice and discrimination.

Since 1960, when Lee's novel was first published, new opportunities emerged through scientific and technological progress which allow us to 'climb into someone's skin' in a more literal sense. For example, following the experimental paradigm of a Rubber Hand Illusion (RHI, [10]), it is possible to induce the illusory sensation of owning a hand with a different skin colour [22, 47]. Moreover, one can even perceive illusory ownership over an entire body with a different skin colour [4, 61], age [3, 72] or gender [45, 60] in a Virtual Reality (VR) environment. Such sensations are called body ownership illusions or body swap illusions.

Recent research suggests that such body swap illusions can affect attitudes towards the group that was embodied. For example, for white-skinned individuals, embodying a dark-skinned rubber hand or avatar has been shown to decrease implicit negative associations with dark-skinned individuals [22, 61] and the effect can last for at least one week after the experience [4]. Bodily illusions have not only been used to study body ownership and changes in social cognition. Instead, previous research mostly induced bodily illusions to investigate the structure and malleability of the mental body representation. This line of research focuses on altering the perception of one's *own* body instead of creating the illusion of owning the body of a different person. For example, by altering the auditory feedback from body-environment interactions, one can induce the illusion of having a heavier or lighter body [73] or a different body height [75].

While previous research showed that (I) bodily illusions can change the mental representation of the body and that (II) body swap illusions can affect implicit attitudes towards the embodied group, the mechanism behind the effect of body swap illusions on social cognition is not fully understood. A recent theory [48, 80] draws on the research on mental body representations in order to explain the observed effects of body swap illusions on social cognition. In this theory, Maister et al. [48] and Tsakiris et al. [80] propose that body swap illusions first cause changes in the mental representation of one's own body and one's self-concept to incorporate more features of the embodied group, and thereby increase the identification with that group. Two recent studies provided evidence for the effect of body swap illusions on the self-concept [3, 72], by showing that individuals associated themselves stronger with child attributes after experiencing a body swap illusion with a child avatar. Such a change in the self-concept is expected to lead to a generalization of one's (positive) self-evaluation to the embodied group, resulting in more positive implicit attitudes [48].

However, the effect of bodily illusions of one's own body (as opposed to body swap illusions) on the self-concept and social cognition has not yet been investigated. The effects of alterations of one's own body perception are relevant because this perception (and the body itself) might naturally change throughout life. If one's body perception is related to one's self-concept and social cognition, then these could situationally differ depending on the current state and perception of our body. To address this gap and to better understand the *how* bodily illusions influence social cognition, this thesis investigates the effect of changing one's own body perception on the self-concept and relation to social (out-) groups.

Furthermore, whilst the majority of research on bodily illusions and social cognition focused on racial biases, other biases, such as gender biases, received less attention. Despite undeniable progress towards more gender equality, gender biases still exist and can foster discrimination, for example in the workplace [9]. If the same principles apply for gender biases as for racial biases, bodily 'gender illusions' during which men embody women and *vice versa* could temporarily alter the self-concept to incorporate more features of the embodied gender group, subsequently increase identification with the embodied gender group, and potentially alter implicit attitudes. Temporarily changing one's gender identification could also be an opportunity to avoid or reduce negative effects on performance in stereotype threatening situations; *i.e.* situations, in which individuals are expected to perform worse based on stereotypes [53].

While bodily illusions are often created through tactile and visual sensory modalities (*e.g.*, in the RHI [10]), other sensory information, such as auditory cues, can also alter body perception [76, 78]. Tajadura-Jiménez et al. [73] found that altering the frequency components in footstep sounds in real-time during walking created the illusion for the walker of having a lighter or heavier body. Also, walkers reported to feel more feminine or masculine during the different sound conditions [77]. The frequency components in step sounds are indicators for both the weight and the sex of the walker [38]. Therefore, if we hear 'heavy' footsteps sounds we associate these with a person who is likely to be heavy and male. Altered footstep sounds may therefore not only induce a 'body weight illusion' but also a 'gender illusion'. This thesis explores this possibility from a theoretical and an empirical angle.

Specifically, this thesis presents two experiments with 26 cisgender females and males respectively, to investigate the effect of real-time alteration of footstep sounds during walking on (I) the self-reported perceived masculinity and femininity of the participants (*bodily feelings*, replication of the findings in [77]), (II) the implicit association of the self with 'female' and 'male' gender categories (*self-gender association*), and (III) the perceived closeness of the self to the group of men and women (*gender group identification*). For an exploratory analysis of potential changes in gait (*i.e.*, potential adoption of gender stereotypical gait patterns), movement data were collected.

To foreshadow results, the findings partially replicate the results from [77] in relation to self-reported *bodily feelings*, showing that after walking with high frequency step sounds, both women and men feel more feminine. Furthermore, women identified more strongly with the group of women after walking with high frequency step sounds (*gender group identification*). Men associated themselves relatively stronger with the female gender after walking with high frequency step sounds (*self-gender association*). This thesis contributes to the research on bodily illusions and social cognition by exploring auditory cues as a sensory modality for inducing bodily (gender) illusions. The results provide evidence for the theory that illusions of one's own body can impact identification with social gender groups and the self-concept; an important step towards understanding the effects of bodily illusions on implicit associations.

Researching and improving our understanding of social cognition, gender identity and their malleability is also important for the field of Artificial Intelligence (AI). One aspect of AI research is to explore the fundamentals and workings of human intelligence and cognition. Experiments investigating the connection between physiological experiences and higher-level cognition can inform theory and models of human behaviour. Cognitive models allow us to implement and test theories on the underlying processes of social cognition (see *e.g.* [8]), and collecting empirical data is necessary for constructing and evaluating such models. This thesis contributes to this line of AI research by collection two relevant datasets on this topic, in which a connection is made between physiological measures, subjective experience, and implicit attitudes. The experiments were designed and analysed with respect to a recent theoretical account and aid our scientific understanding.

In addition, there is value for practice and AI applications. There are already several commercial services that use algorithms to classify individuals as male or female, for example based on images of faces [68]. If these classifications are used for example for profiling, they could cause harm through misclassification and potentially perpetuate existing biases (*e.g.*, by recommending gender-typed products, job adverts etc.). Therefore, to improve the design and critically consider the use of automatic gender classification systems, it is important to gain a better understanding of the development and malleability of gender identity.

In the following, I will first cover related literature on multisensory integration and bodily illusions, predictive coding as an explanatory framework, the relation of bodily illusions to social cognition, and how a 'gender illusion' could be induced (Chapter 2). Based on the reviewed literature, three hypotheses are formulated (Section 3.1) and tested in an experiment with cisgender females (Chapter 3 & 4). Prior work suggested that the perception of the altered footstep sounds is not influenced by participant's sex [77]. However, it was suspected that men could experience a 'masculinity threat' in response to the altered footstep sounds, hence, that they would feel the need to re-establish or defend their masculinity because they perceived walking with feminine sounding footsteps as a threat to their masculinity [83]. Given these expectations and due to reasons of statistical power, the experiment only focused on women. After the completion of this experiment, time and resources allowed for the conduction of a second experiment involving cisgender males. This second experiment is described in Chapter 5 & 6. As the findings in the two experiments differed and the experimental protocols were almost identical, Chapter 7 presents an analysis of the combined datasets to explore potential interactions with the participant's sex. The findings and implications are discussed in Chapter 8 and the thesis is concluded in Chapter 9.

# 2 Related work

### *2.1 Multisensory integration and bodily illusions*

To understand how bodily illusions can be induced, we must understand the concept of *multisensory integration*. Multisensory integration refers to the process in the brain which combines information from multiple senses. This process is crucial for the processing and interpretation of information [71], and the coordination of movement behaviour [84]. Furthermore, multisensory integration forms the basis for a mental representation of our body in our brain. This representation is constructed and continuously updated through multisensory integration [16, 50, 51]. The relationship between sensory inputs from different modalities is complex and discrepancies between information from different senses can lead to strong perceptual illusions, such as the McGurk effect [54]. In this effect, lip movements alter the sounds being heard during speech processing which shows the integration of visual and auditory sensory information. Multisensory integration is also considered to be essential to perceive *ownership* over the body and distinguish it from other objects [15, 39]. Thus, through experimentally creating discrepancies between sensory modalities that provide information about the body, it is possible to induce so-called *bodily illusions*. During these illusions, the body is perceived differently from its actual state. In this thesis, I will experimentally alter auditory information of body-environment interactions in real-time to induce a bodily illusion.

A wide variety of bodily illusions have been reported in the literature. The first experimental paradigm showing the malleability of mental body representations is the Rubber Hand Illusion (RHI [10]). In the RHI, a rubber hand is placed in front of the participant while their real hand is hidden from their view. Then, the rubber hand is stroked synchronously with the participant's real hand. In most cases, the correlation of visual and tactile information causes the participant to perceive the rubber hand as their own hand. This change in perceived ownership is self-reported by the participants but also becomes apparent in more "objective measures" of the RHI (see [15] for an overview), such as a proprioceptive drift towards the rubber hand [10], a decreased skin temperature in the real hand (see [57], but also [64] for contradicting evidence), and increased histamine reactivity in the real hand [6]. Building on the findings from the RHI, there are many other body illusions during which individuals can perceive their own bodies to have different dimensions, such as a different height [75], weight [73], an elongated finger [74] or arm [76]. It is also possible to induce ownership over entirely different bodies [42, 62]. Especially with the help of VR, participants can experience ownership over a body in the size of a Barbie doll [81], a children's body [72] and bodies with a different race [61], age [5], and also gender [45, 60]. The latter, so-called *body ownership illusions* or *body swap illusions*, have been recently used to investigate social cognition. In this work, I aim to extend the research on social cognition to illusions of changes in one's *own* body (as opposed to body swap illusions).

### *2.2 Explanation for bodily illusions*

While bodily illusions show that the perception of one's body can be altered through multisensory integration, it is not clear *why* this is the case. The seemingly simple process of recognising the body as one's own is not fully understood from a theoretical perspective. Different theoretical frameworks have been proposed for explanation, one of them is the predictive coding account (but see [39] for an overview). This account forms the theoretical basis for a connection between body perception and social cognition.

The predictive coding account [13] proposes that sensory information is processed in a hierarchical model which combines top-down and bottom-up processes. The top-down processes are predictions of the brain about future sensory inputs. These predictions are based on prior knowledge about the body and the environment. For example, when grasping a glass, the brain predicts the trajectory of the grasping movement and the tactile sensation upon touching the glass shortly before the movement is executed. The bottom-up processes are prediction *errors* that occur when comparing the predicted sensory activation with the actual sensory activation upon interaction. For example, if one misjudged the position of the glass and only grasped empty air instead of the glass, this causes a mismatch between the predicted and received sensory input. This mismatch elicits an error signal or "surprise" which will be propagated to the higher levels of the hierarchical model. The predictive coding account assumes that each level in the hierarchy generates predictions for the levels below and that these predictions are constantly updated in order to reduce the occurrence of prediction errors [13].

Apps and Tsakiris [1] applied the predictive coding account to self-recognition and body perception. Within this account, they suggest that the body is processed in a probabilistic way, meaning that, "*one's own body is the one which has the highest probability of being "me" as other objects are probabilistically less likely to evoke the same sensory inputs*" (p. 88) [1]. In the case of for example the RHI, the multisensory stimulation creates a considerable amount of surprise because the brain does not predict receiving tactile sensory information from the rubber hand as it is not a part of the body. However, while watching the rubber hand being touched, the brain still receives the corresponding tactile sensation. This mismatch between predicted and received sensory activation, *i.e.* the prediction error, is propagated to the higher levels of the hierarchy. In the higher levels of the hierarchy, this conflict can only be resolved by updating the probability of the rubber hand to be a part of "me", hence, by updating the mental body representation. Consequently, as the rubber hand is perceived as a part of one's body, the higher levels predict the tactile sensory activation when the rubber hand is touched and therefore, no (or less) prediction errors will occur. In this thesis, based on the principles of predictive coding and multisensory integration, I explore the possibility of inducing a temporary change of perceived gender identity (*i.e.*, perceived masculinity and femininity, self-gender association and identification with gender groups) through altering auditory feedback from body-environment interactions.

### *2.3 Bodily illusions and social cognition*

There is accumulating evidence that bodily illusions do not only affect the inner representation of the body but also higher-level cognition, such as the self-concept and social cognition (see [48, 80] for an overview). Several experiments found a reduction of implicit racial bias in white-skinned individuals after experiencing a body swap illusion with a dark-skinned avatar [4, 61], face [25] or rubber hand [47]. Hasler et al. [30] investigated non-verbal behaviour between an individual embodied in a virtual character and an animated virtual character in VR. They found increased mimicry behaviour of the participant when both virtual characters had the same (*i.e.* dark or white) skin-colour. The effect occurred regardless of the participants' actual racial group membership. This is an indicator that the body swap illusion caused participants to perceive the embodied racial group as their new ingroup and to adjust their non-verbal behaviour accordingly [30]. Further, experiencing an enfacement illusion has been shown to blur the boundaries between self and other, resulting in participants judging the faces of strangers as closer to themselves [59], and facilitating emotion recognition in the embodied face [49]. These findings provide evidence that changes in body perception during bodily illusions can alter our perception of and attitudes towards others, our in- and outgroup identification, and our self-recognition.

Maister et al. [48] offer an explanation for a potential connection between body swap illusions and social cognition in the context of the predictive coding account. They propose that the higher levels of the hierarchy contain, additionally to body representation, attitudes and beliefs about the self and about social in- and outgroups. These attitudes and beliefs about the self are linked to the representation of the body and can be adjusted in order to maintain consistency between the self and the body representation [48]. In the case of embodying a racial outgroup, the bodily illusion induces an increased perceived physical similarity between the outgroup member and the self. The body representation is updated to overlap more with the representation of the outgroup which is expected to form a link between the self-concept and the racial outgroup. The authors argue that this link facilitates the transfer of self-like associations to the outgroup. As most people have a positive evaluation of themselves, this is would explain a more positive evaluation of the respective outgroup after experiencing a body swap illusion [48].

While the change in the evaluation of the outgroup has been shown in implicit associations (*e.g.*, [61]), there is less research on changes in the self-concept. Banakou et al. [3] and Tajadura-Jiménez et al. [72] found in that embodying a child avatar in VR increased implicit associations of the self with child-like attributes, hence, providing evidence for a link between the self-concept and the embodied group. The idea that the phenotypical overlap between the self and the outgroup representation relates to social cognition is also supported by the finding that we display stronger empathetic responses to faces of racial ingroup members compared to faces of racial outgroup members [86]. However, more research is required to understand if and how social cognition is connected to body perception and bodily illusions. Hence, in this thesis, I focus on changes in self-associations and identification with social groups induced through bodily illusions.

### *2.4 Bodily 'gender illusions'*

Based on the predictive coding account and existing work on racial biases, bodily illusions could provide an opportunity to address gender biases through temporarily influencing gender identification. Joel et al. [34] found that cisgender individuals can perceive aspects of female *and* male gender to be a part of their identity, challenging the view of male and female gender as distinct binary categories. Considering gender identity to be a spectrum, bodily 'gender illusions' could temporarily alter how much individuals associate themselves with and relate to different gender groups.

Several experiments employed VR technology to embody male and female participants in avatars of the respective ‘opposite’ gender [41, 45, 60]. Two of these experiments focused on performance in stereotype threatening situations, *i.e.* situations, in which individuals experience increased stress and working memory load because they are stereotypically expected to perform worse. Peck et al. [60] found that embodying a male avatar can revoke the negative effect of a stereotype threat for females. The impact of stereotype threats is moderated by the strength of gender identification [66], thus, one explanation for this effect is that embodying a male avatar decreased the identification of female participants with the group of women and increased their identification with the group of men. Similarly, regardless of actual gender, participants performed best in an arithmetic task when embodying a male avatar and competing against female avatars [41]. Thus, temporarily changing the strength of gender identification could improve one’s performance in certain situations. Whether such a change in gender identification could be induced through altering auditory feedback is investigated in this thesis.

Lopez et al. [45] investigated changes in implicit gender bias in response to body swap illusions. They created male and female avatars and mapped the movement of participants to the movement of the avatar in VR. Participants were instructed to follow a virtual Tai Chi lesson during which they could observe their movements in a virtual mirror. The synchrony between executed motor controls and the visual feedback in the virtual environment induces the bodily illusion of owning the avatar’s body. They measured the effect on implicit gender biases with a Gender-Career IAT, pairing male and female first names with words relating to ‘career’ and ‘family’. They found an increase in bias towards associating female names with ‘family’ for those participants who embodied a female avatar which is contrary to the expected effect of the body swap illusion. The authors discuss stereotype activation and the challenging situation of following a Tai Chi lesson as potential reasons for this finding [45]. However, it should also be noted that the authors do not relate their work to a theoretical framework. Relating it to the predictive coding account, the illusion of owning a female body is expected to update the body representation to incorporate more features of women, link the self-concept to the group of women, and subsequently lead to a transfer of self-like associations to the group of women. Therefore, a change in Gender-Career associations would require the participants to have Self-Career associations, which could then be transferred to the group of women. This was, however, not measured by Lopez et al. [45] and makes it difficult to interpret their findings. Hence, this study highlights the importance of focusing on the underlying connection between body perception and social cognition when researching implicit (gender) biases.

A recent study by Tajadura-Jiménez et al. suggests that ‘gender illusions’ could be induced through auditory information [77]. In their experiment, participants listened to real-time alterations of their footstep sounds with enhanced high or low spectral frequency components during walking. In the ‘low frequency’ condition (‘heavy’ steps) participants reported to feel more masculine and in the ‘high frequency’ condition (‘light’ steps) participants reported to feel more feminine than in the respective other condition. Within the predictive coding account [1, 13], these results could be explained as follows: while walking, the brain constantly predicts the sensory input it will receive while walking, including the well-known sound of one’s own steps. The frequency components of female and male walkers are distinct and people can distinguish between the genders based on the sounds [26, 44]. Low frequency footstep sounds are associated with a male and heavy walker, and wearing flat shoes, while high frequency step sounds are associated with a female and light walker, and wearing high heels [44]. For a female individual, the brain is expected to predict more high-frequency footstep sounds during walking. However, in the ‘low frequency’ condition, the walking sounds differ substantially from the ones predicted. The mismatch between predicted high frequency and heard low frequency sounds creates prediction errors. To resolve the conflict and reduce the occurrence of prediction errors, the body representation is updated to be relatively more likely to be male and less likely to be female [1].

Connecting the predictive coding account again to social cognition [48, 80], the updated body representation is expected to also influence the self-concept and the in- and outgroup identification of the individual. In the example of the female individual walking with low frequency footstep sounds, it would be expected that she associates herself more with 'male' gender and feels closer to the group of males during and immediately after walking with the altered footstep sounds. The present work aims to explore this effect experimentally.

### *2.5 Assessing changes in social cognition with the IAT*

The Implicit Association Task (IAT) [27] is a general-purpose task that measures the strength of implicit associations between concepts (*e.g.*, in this experiment 'male', 'female,' 'self', and 'other') based on reaction time. Each concept is represented by words which will appear after one another in the centre of the screen. Participants are asked to sort the words into concepts presented on the left and right side of the screen. In the important sections of the task, participants must sort the word stimuli corresponding to *two* concepts on each side (*e.g.*, left: 'other & female', right: 'self & male'). The underlying idea behind the IAT is that if the two concepts are associated with each other, participants can sort stimuli quicker into those categories than if the two concepts are not associated. The IAT score results from the difference between the block in which the concepts are congruent with the expected association and the block in which the concepts are incongruent with the expected association. For example, women would be expected to have a stronger association for self and female and hence, to sort the words quicker into the congruent categories 'self & female' and 'other & male' compared to the incongruent categories of 'self & male' and 'other & female'.

In the context of bodily illusions, the IAT has been frequently used to assess changes in implicit racial bias [4, 23, 25, 47, 61] and gender bias [45] after embodying the full body or body parts of outgroup members. Banakou et al. [4] argue that body perception influences implicit attitudes "*below the threshold of consciousness*" (p. 9) and although participants do not explicitly report that their bodies or attitudes changed, a change in the IAT score provides evidence for this relation. Although bodily illusions are hypothesized to blur the boundaries between self and other [59], increase self-association with the embodied outgroup member [48] and change higher-level concepts of the self [80], only few experiments specifically measured these aspects. Two examples are Banakou et al. [3] and Tajadura-Jiménez et al. [72] who used an IAT to assess changes in the self-concept by pairing words describing 'me' and 'other' with images of children and adults. Given its widespread use, especially for investigating the effect of body swap illusions on social cognition and its applicability to the study goals, the IAT is an important measurement for the presented study.

# 3 Experiment I – Women

### *3.1 Aim and hypotheses*

In this experiment, I investigated whether modifying footstep sounds real-time to sound more feminine or masculine [44] during walking affects women's self-association with 'male' and 'female' gender categories as well as their perceived closeness to the group of women and men. The aim of the experiment was twofold: first, to validate the effect of altered footstep sounds on perceived masculinity and femininity reported in prior work [77] and second, to add to the ongoing research on the relationship of bodily illusions and social cognition [3, 72] by focusing on auditory feedback and gender identity. The following three hypotheses were formulated:

**H1**: The step sounds will affect *bodily feelings*. Based on the connection between frequency components in footstep sounds and the sex of the walker [44], and previous research on inducing bodily illusions through altering footstep sounds [73, 77], it was expected that women will feel lighter and more feminine after walking with high frequency step sounds compared to low frequency step sounds.

**H2**: The step sounds will affect s*elf-gender associations*. Based on the theory that bodily illusions affect the self-concept by increasing associations of the self with the embodied group [3, 48, 80], it was expected that high frequency step sounds will enhance self-female associations and that low frequency step sounds will enhance self-male associations.

**H3**: The step sounds will affect s*elf-gender group identification*. Based on the theory that bodily illusions can increase identification with the embodied group [48, 80], it was expected that high frequency step sounds will increase identification of the self with the group of women, and that low frequency step sounds will increase identification of the self with the group of men.

To test these hypotheses, I conducted a lab experiment during which participants walked with modified footstep sounds (female-typical and male-typical) and measured their experience before and after the intervention.

### *3.2 Participants*

Prior to the experiment and based on the masculine-feminine difference between high and low frequency reported by Tajadura-Jiménez et al. in [77], a power analysis was conducted with the software G*Power (v. 3.1) [24] using the settings $\alpha = .05$, $d = .72$, and a directed hypothesis. The recommended sample size given these requirements was 24 participants.

In this experiment, 26 female cisgender participants took part. They had a mean age of 26.3 years ($SD = 4.46$ years). On average, they weighed 58.73 *kg* ($SD = 9.71$ *kg*) and were self-reportedly 164.6 *cm* ($SD = 7.81$ *cm*) tall. Their mean body mass index of 21.7 ($SD = 3.03$) was in the normal range. The participants originated from 16 different countries with 6 participants originating from a country in which English is the primary language.

Participants were recruited through an online subject pool, flyers, the social network of the experimenter, and by asking people on campus. In return, participants could choose to participate in a raffle for one of three £30 Amazon vouchers (20 participants), to recruit the experimenter for their own experiment (6 participants) or to receive one academic credit (0 participants).

The study was approved by the UCL Research Ethics Committee (Project ID: UCLIC/1516/003/ StaffBerthouze/Newbold) and all participants provided written informed consent prior to their participation. The information sheet and consent form are displayed in Appendix E.

### *3.3 Materials*

In this experiment, participants walked with two types of modified footstep sounds in one ‘walking phase’ respectively. During these walking phases, participants wore a set of equipment in order to alter footstep sounds in real-time and to capture behavioural data. The full set-up is displayed in Figure 1. The experiment was conducted in a quiet room and participants walked on a 3.6 x 0.6 *m* wooden corridor (medium density fibre, 2.5 *cm* thick).

*Real-time sonification.* The equipment for altering footstep sounds in real-time involved a pair of strap-sandals similar to the one used by Tajadura-Jiménez et al. [73]. These sandals had a hard rubber sole and produced clear contact sound on the wooden corridor during walking. In order to record and consecutively alter the footstep sounds, small microphones (Core Sound) were attached to each of the sandals. These microphones were connected to a preamplifier (FoneStar, TC-6M) to increase the volume of the recorded sounds. The preamplifier was connected to a stereo 9-band graphic equalizer (Behringer FBQ800) which allowed the enhancement or diminution of the volume of certain frequency components in the sounds. During walking, the participants heard their modified footstep sounds through noise-muffling headphones (Sennheiser HDA 300). The preamplifier and equalizer were fitted into a small backpack for the participant to carry.

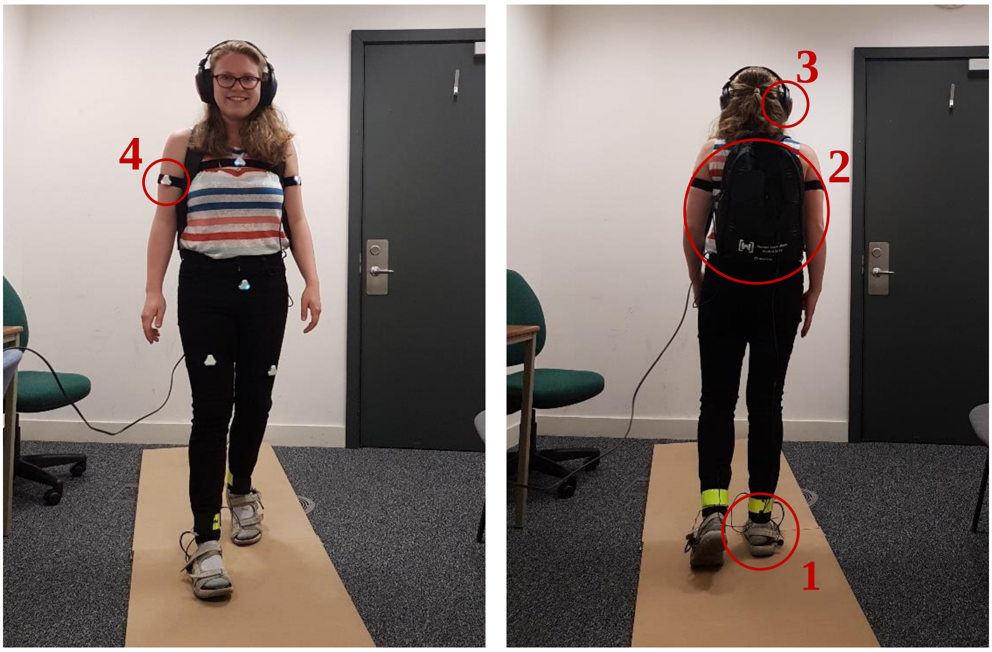


*Figure 1: Equipment during the two walking phases. Participants wore strap-sandals with attached microphones (1), a small backpack containing a pre-amplifier and an equalizer (2), and headphones through which participants heard their modified footstep sounds (3). Black rubber bands with one of six Notch movement sensors (white triangles) each (4) were attached to the upper arms, chest, hip, and thighs.*

*Behavioural changes.* Altered body representations can cause changes in behaviour, such as arm reaching movements [76] or step size [75]. Therefore, movement data was collected to capture potential changes in gait in response to the bodily illusion induced through altered footstep sounds. Previous research on differences in masculine and feminine gait found that females exhibit more lateral hip sway, while men exhibit more lateral more shoulder sway during walking [52]. The bodily illusion could cause participants to adjust their walking behaviour to resemble masculine walking patterns more closely in the low frequency condition and feminine walking patterns in the high frequency condition. Thus, to measure lateral hip and shoulder sway, each participant wore 6 Notch movement sensors [58] attached with rubber bands to their upper arms, thighs, chest and hips (Figure 1). The movement data was recorded with the Notch Pioneer Motion Capture application (v. 1.10.0) on an Android Samsung Galaxy S7 Smartphone.

*Self-gender associations.* An Implicit Association Task (IAT) [27] was used to assess (implicit) self-association with ‘male’ and ‘female’ gender categories both prior to and following the walking phases. The stimuli for this IAT were selected based on the gender IAT reported in [14] and the order of the blocks was counterbalanced. The IAT was implemented in Qualtrics with the ‘iatgen’ package [12].

*Baseline gender identity.* Participants were asked to answer the Traditional Masculinity-Femininity (TMF) scale [35] to assess their self-ascribed masculinity and femininity. The aim was not to classify whether someone is very feminine or masculine with respect to others or society but to capture their subjective experience. The scale consists of 6 questions with answer options ranging from ‘typically masculine’ to ‘typically feminine’. This scale was chosen because it does not refer to specific (cultural or generational) feminine and masculine characteristics or traits and should therefore be applicable to a diverse sample. The first two questions, “I consider myself to be…” (masculine-feminine being) and “I wish to be…” (masculine-feminine wish) closely resemble the ones used by Tajadura-Jiménez et al. [77], which this work is based on.

*Self-gender group identification.* Identification with the group of women and men was measured with the Inclusion of the Other in the Self (IOS) scale [2], which is a pictorial measure of closeness and consists of seven pictures, each displaying two circles of decreasing distance. The IOS has been used for measuring identification with different social groups [67], and also for assessing gender identification [31]. In this experiment, one circle represents the 'self' and the other circle represents the group of women (IOS Women) or the group of men (IOS Men) respectively (Figure 2). Participants were asked to select the picture that represents their relationship to the respective group best. The closer the circles are to one another, the closer is the perceived relationship to the group.


*Figure 2: First image from the IOS scale. The small circle represents the self, the large circle represents the group of women (or men in the IOS Men). The proximity of the circles decreases in the following six images and participants were instructed to choose the image that represents their relationship to the displayed group best.*

*Emotional state and bodily feelings.* Analogous to previous work [77], bodily feelings were measured with three statements: I felt… "light" to "heavy", "weak" to "strong", and "very feminine" to "very masculine" on a 7-point Likert scale. These self-report questions were used to measure whether the altered footstep sounds affected participants similarly as in previous research using altered footstep sounds, and hence, whether the bodily illusion was induced successfully. Further, similar to previous work [77], emotional state was measured with self-assessment manikins [11] on a 9-point scale respectively for valence, arousal and dominance. Based on these questions, it was assessed whether the emotional experience of the participants differed between the sound conditions.

*Shape and weight concerns.* Previous research has shown that individuals with a (history of) eating disorders differ in their body perception and sensitivity to bodily illusions [17, 18]. Not having any (history of) eating disorders was part of the selection criteria for the participants. However, to assess differences in this dimension, participants were asked to answer two subscales of the Eating Disorder Examination Questionnaire (EDE-Q) for weight and shape concern [19, 20].

*Inferred purpose and prior experience.* Participants were asked to describe what they thought the experiment was about. Further, they were asked whether they had completed an IAT before taking part in the experiment, if they had heard of the shoe-prototype before, and - if so - knew that it could influence their body weight perception. These questions were asked to gain a better understanding of the participant's interpretation of the experiment, as well as relevant prior knowledge that might have influenced their experience of the altered footstep sounds.

*Demographics.* Lastly, participants were asked to provide some demographic information on their age, gender, and country of origin. Furthermore, previous work [77] identified body weight as a relevant factor for the effect of the sounds. To assess whether participants had a 'normal' body mass index, they were asked for their body height and their body weight was measured.

*3.4 Experimental design*

*Sound feedback conditions.* The hypotheses were tested in a within-subject design with two sound conditions; high and low frequency. In the 'high frequency' condition, frequencies in the range of 1-4 kHz were amplified by 12 dB and the frequencies in the range of 83-250 Hz were attenuated by

12 dB. Conversely, in the 'low frequency' condition frequencies in the range of 83-250 Hz were amplified by 12 dB and frequencies in the range of 1-4 kHz were attenuated by 12 dB. These sound conditions are identical to the ones used in previous work [73, 77]. Each participant completed two walking phases, one in the high frequency condition and one in the low frequency condition. The order of the sound conditions was counterbalanced across participants.

### *3.5 Procedure*

After arriving in the lab, participants received an information sheet with a general overview of the experiment. They were given the opportunity to ask any questions and were then asked to sign an informed consent form. In the first part of the experiment, participants completed the IAT for self-gender association. The instructions for each part of the IAT were provided on the screen, but participants were encouraged to ask the experimenter if anything was unclear. After completing the first IAT, participants answered a set of questions (TMF, IOS Women, IOS Men). For the following first walking phase, participants were assisted in attaching the Notch movement sensors to their body, in putting on the shoe-prototype and the backpack. The experimenter then attached one microphone each to the outside of the left and right sandal. Then, the participants were asked to stand at the beginning of the wooden corridor. After the calibration of the Notch movement sensors, participants received instructions for the walking phase. Before starting the walking phase, the experimenter controlled for the adequacy of the sounds and then handed the headphones to the participants. After a visual starting signal, participants marched on the spot for 30 seconds and paused briefly after a visual stop signal. Following a second visual starting signal, they walked down the corridor and paused at the end. Two separate recordings of movement data were collected in the Notch app, one for walking on the spot and one for walking down the corridor. After the walking was completed, participants took off the headphones and the experimenter removed the microphones and the backpack. Immediately afterwards, participants were asked to sit down and complete the IAT task again. Upon completion of the IAT, participants answered the second set of questions (IOS Women, IOS Men, bodily feelings, SAM). This procedure was repeated with the second sound condition. At the end of the experiment, participants answered additional questions on their weight and shape concern, thoughts on the purpose of the experiment, prior experience, and demographics. Finally, after taking off the Notch sensors and sandals, participants were asked about their body height and to step on a scale to measure body weight. All participants were fully debriefed. An overview of the tasks and questionnaires is provided in Figure 3.

| **Baseline** | Walking with HF or LF sounds | **Post-experience I** | Walking with HF or LF sounds | **Post-experience II** | **General** |
|---|---|---|---|---|---|
| IAT<br>TMF<br>IOS (Women, Men) | | IAT<br>IOS (Women, Men)<br>Bodily feelings<br>SAM | | IAT<br>IOS (Women, Men)<br>Bodily feelings<br>SAM | EDE-Q subscales<br>Purpose<br>Prior experience<br>Demographics |

*Figure 3: Overview of the experimental procedure. The order of the sound conditions (HF and LF) was counterbalanced.*

### *3.6 Measurements*

Below I define the exact measurements to test the hypotheses and assess other potentially relevant factors which characterise the participant group. For each of the described analyses of the hypotheses, an equivalent Bayesian analysis was performed in the software JASP (v. 0.11.1) [33]. The Bayes factor is reported ($B_{10}$ – in support of the alternative model; $B_{01}$ – in support of the null model) complimentary to each frequentist analysis. The Bayes factor indicates how likely it is to find certain data if the alternative (or null) model is true, *i.e.* $BF_{10} = 9$ indicates that it is 9 times more likely to find the given results if the alternative model is true. The following classification for the strength of evidence, as indicated by the Bayes factor, was used: 1 – 3 is weak, 3 – 10 is moderate, and 10 – 30 is strong evidence [82].

*Bodily feelings (H1)*. The questions to assess femininity-masculinity, light-heavy, and weak-strong perception used a seven-point Likert scale. To compare the answers after walking in the high and low frequency condition, non-parametric Wilcoxon signed rank tests were calculated for each of the three questions.

*Self-gender association (H2)*. The self-gender association IATs were analysed with the improved IAT scoring algorithm reported by Greenwald et al. in [28], which is also implemented in the 'iatgen' package [12]. In this experiment, a positive IAT score indicates a self-female association (0 to +2) and a negative IAT score indicates a self-male association (0 to -2). A repeated measures ANOVA was calculated to compare the baseline, after high, and after low frequency condition IAT scores. Paired t-tests were used for pairwise comparisons and *p*-values were adjusted for multiple comparisons with the Bonferroni correction.

*Self-gender group identification (H3)*. The seven images of the pictorial IOS scale were coded with numbers from 1 to 7 for the analysis. Increasing numbers correspond to a closer proximity between the circles. For both, the IOS with the group of men and the IOS with the group of women, a non-parametric Friedman test was calculated to compare the measures at the beginning of the experiment, after the high, and after the low frequency condition. Non-parametric Wilcoxon signed rank tests were used for pairwise comparisons and *p*-values were adjusted for multiple comparisons with the Bonferroni correction.

*Behavioural changes.* The analysis focused on the walking phase on the corridor; the data from walking on the spot was not analysed any further. CSV files with lateral angles from hip and chest movement were extracted from the Notch application. Initially, an R script was developed for automatic identification and analysis of peaks and valleys in the hip and chest angles. However, due to the short walking phase and large variation within the data, the automatic annotation performed poorly in some cases. Upon reviewing the identified peaks and valleys with an expert, it was decided to annotate them manually to avoid misclassifications. Hence, lateral hip and chest angles were plotted in MATLAB and peaks and valleys were annotated and extracted with the 'data cursor mode'. Despite the short walking phase, the annotation aimed to extract two or three 'representative' steps. To identify these, only peaks and valleys that were part of a reoccurring pattern were annotated. Hence, if *e.g.* the amplitude of the first peak was very high and the consecutive three peaks and valleys had a lower, comparable amplitude, only these three peaks and valleys were extracted. In some cases, the signal did not allow for a clear annotation of peaks (see Appendix A for and example).

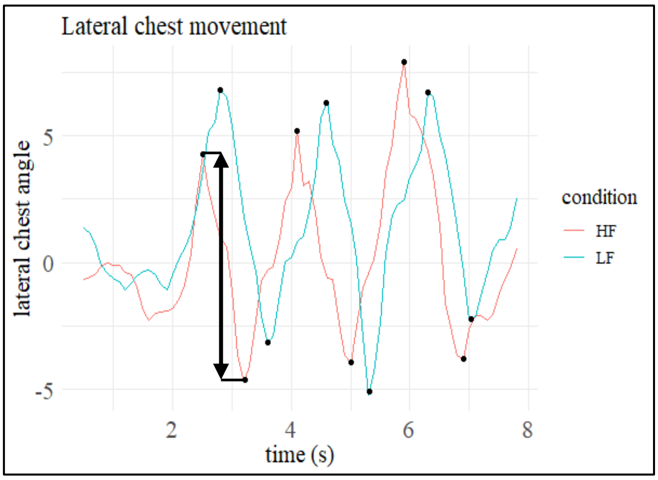


*Figure 4: Example plot of lateral chest tilt in high and low frequency. The black dots represent the annotated peaks and valleys. I calculated the absolute differences between a consecutive peak and valley (black arrow). Based on these distances, two values were extracted: the average distance (sum divided by the total number of peaks & valleys) and the maximal distance.*

The manually annotated peaks and valleys were analysed in R and two values were extracted from each walking phase: the average difference between a consecutive peak and valley (sum of distances between a consecutive peak and valley divided by total number of peaks and valleys) and the maximal difference between a consecutive peak and valley (see Figure 4). The resulting data was not normally distributed; therefore, Wilcoxon signed rank tests were used to compare the mean and maximal lateral sway between low and high frequency.

To test whether the data from typically masculine and feminine walk would differ in lateral hip and chest angles, as measured by the Notch sensors, trial recordings during which the experimenter mimicked these walking styles were collected with the Notch sensors and analysed in R. These recordings showed the expected difference in lateral hip and chest tilt between masculine and feminine walking (see Appendix A).

*Baseline gender identity.* Corresponding to the procedure reported by Kachel et al. [35], the answers to the TMF scale were coded with numbers from one to seven. For the analysis, the mean score from all six questions was calculated. The TMF scale is relatively new, therefore, there are no community norms available yet. However, in the original publication of the scale, mean TMF values of 4.54 ($SD$ = 1.15) and 5.36 ($SD$ = 0.72) were reported for lesbian and straight women respectively [35]. As sexual orientation was not assessed during this experiment, a t-test was calculated to compare the mean TMF score with the average ($M$ = 4.95) of both values reported by Kachel et al. [35] to account for a potential diversity of sexual orientation in the sample. Additionally to the overall mean TMF score, the individual answers to the first (masculine-feminine being) and second (masculine-feminine wish) question were extracted as these questions correspond to the questions used by Tajadura-Jiménez et al. [77], which this thesis is based on. To assess whether masculine-feminine being and wishes were similar in the samples, the median scores of women and men for these two questions were compared with the corresponding median scores reported in [77].

*Shape and weight concerns.* To analyse the weight and shape concern of the participants, following the coding instructions provided by Fairburn et al. [19], the answers to the subscales were coded with numbers from zero to six. The average rating was calculated for the items corresponding to the shape and the weight concern subscales respectively, and compared the scores to the community norms for US [46] and Australian [56] undergraduate women.

# 4 Results Experiment I – Women

The questionnaire data of one participant were excluded from the data set due to indicators of *content nonresponsivity* [55] as the participant gave the same answer to many consecutive questions suggesting that she did not read and respond to the content of the question. Hence, the analysis of the questionnaire data (H1 and H3) is based on 25 participants.

## *4.1 Analysis of hypotheses*

<u>Bodily feelings (H1)</u>

After walking with high frequency step sounds, participants reported to feel significantly more feminine ($Z = -3.49$, $p < .001$, $r = .54$), lighter ($Z = -3.46$, $p < .001$, $r = .69$), and weaker ($Z = -2.34$, $p < .05$, $r = .46$) than after walking with low frequency step sounds. An overview of the answers to the bodily feelings questions is displayed in Figure 5.

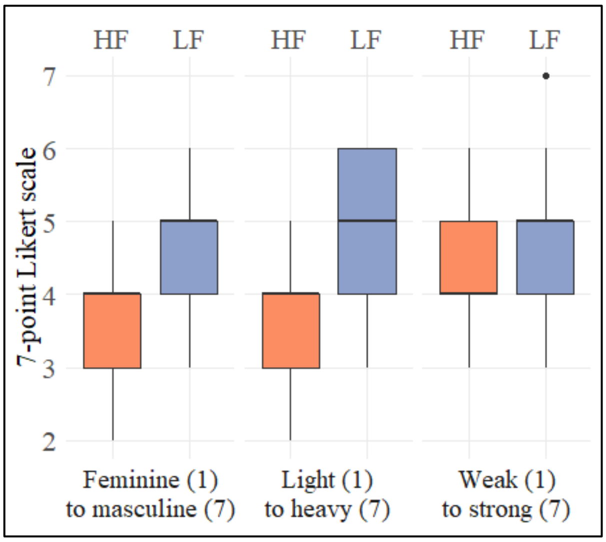


*Figure 5: Answers to the bodily feelings questions on perceived masculinity and femininity, body weight, and strength in the high frequency and low frequency condition.*

The Bayes factor indicates very strong support for the difference in the light-heavy dimension ($BF_{10}$ = 201.87) and in the feminine-masculine dimension ($BF_{10}$ = 378.25). For the weak-strong dimension, the evidence is weak ($BF_{10}$ = 2.35), hence, a difference in perceived strength between the sound conditions cannot be inferred with certainty from this data.

Self-gender association (H2)

In the baseline measure, as expected, female cisgender participants associated themselves implicitly stronger with 'female' than with 'male' gender categories (IAT score: $M$ = 0.38, $SD$ = 0.4). The distribution of IAT scores at the three points of measurement is displayed in Figure 6. Contrary to the formulated hypothesis, self-gender association was not significantly affected by the walking sounds, $F(2, 50) = 0.366$, $p = .695$, $\eta^2 = .004$, $n = 26$. A detailed overview of the three IAT scores for each participant is provided in Appendix B. No further comparisons were calculated.

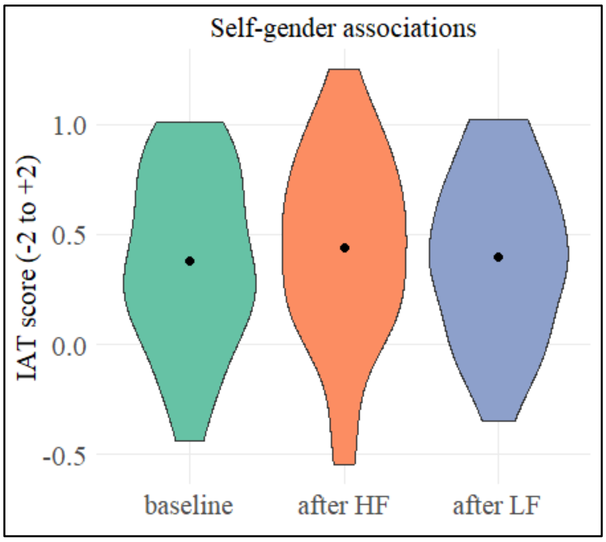


*Figure 6: Distribution of IAT scores (-2 to +2) in the group of women. The black dots indicate the mean IAT scores. A positive score corresponds to a quicker association of 'self' and 'female'. A negative IAT score indicates a quicker association of 'self' and 'male'.*

<u>Self-gender group relation (H3)</u>

In the baseline measure, women reported to feel closer to the group of women (*M* = 5.32, *SD* = 1.14) than to the group of men (*M* = 3.68, *SD* = 1.28). Comparing both ratings showed that five participants felt equally close to the group of women as to the group of men.

The perceived closeness to the group of women at the three points of measurement is displayed in Figure 7. There was a significant difference between the three points of measurement ($\chi^2(2) = 8.18$, $p = .017$, $n = 25$) with women reporting to feel closer to the group of women after walking with high frequency step sounds ($Z = -2.47$, $p_{adj} = .04$, $r_{adj} = .49$). This is supported by a Bayes factor of $BF_{10} = 3.13$, which is just about moderate evidence in favour of the alternative model.

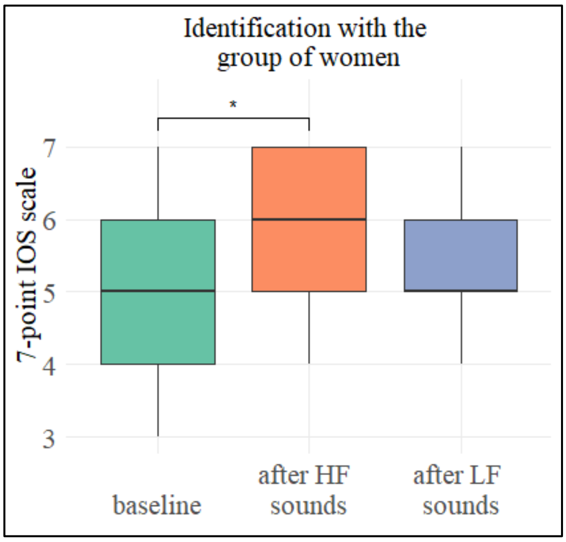


*Figure 7: Answers to the IOS scale at the three points of measurement. The horizontal bar represents the mean IOS score. A higher score indicates a closer relationship between the self and the group of women.*

The relationship to the group of men (IOS Men) did not differ between the three sound conditions ($\chi^2(2) = 0.5$, $p = .78$, $n = 25$). Accordingly, the Bayes factor indicates moderate evidence against the alternative model ($BF_{01} = 6.78$). No further comparisons were calculated.

<u>Movement behaviour</u>

No Notch movement data was recorded for one participant and one other recording was lost due to technical failure. One participant was excluded from the analysis because peaks could not be unambiguously identified from the movement data. Table 1 provides an overview of the extracted peaks and valleys in hip and chest movement during walking with high and low frequency footstep sounds.

*Table 1: Descriptive data of peaks and valleys in lateral hip and chest movement (mean and maximal amplitude, mean number)*

| | **Avg. *M* (*SD*)** | **Avg. *Max* (*SD*)** | **Avg. # of peaks (*SD*)** |
|---|---|---|---|
| Chest high frequency | 4.77 (1.65) | 7.81 (2.41) | 6.17 (1.40) |
| Chest low frequency | 4.90 (1.90) | 7.80 (2.54) | 5.96 (0.928) |
| Hip high frequency | 5.75 (1.90) | 9.13 (2.20) | 6.13 (1.10) |
| Hip low frequency | 5.83 (2.42) | 8.78 (3.12) | 6.17 (1.15) |

There was no difference in average ($Z = -0.015$, $p = .988$, $r = .003$) or maximal ($Z = -1.655$, $p = .098$, $r = .331$) lateral hip tilt between high and low frequency. Similarly, there was no difference in average ($Z = -0.254$, $p = .8$, $r = .051$) or maximal ($Z = 0$, $p = 1$, $r = 0$) lateral chest tilt.

*4.2 Influencing factors*

The purpose of the following section is (I) to assess whether the gender identity, shape and weight concerns of the sample were comparable to available community norms, hence, whether the findings are likely to apply to other women as well, and (II) to provide more information on prior knowledge of the participants and their interpretation of the purpose of the experiment, as this might have influenced their experience and responses during the experiment.

*Baseline gender identity*. The mean TMF score was 4.92 (*SD* = 0.66) and did not differ from the mean of the scores for lesbian and straight women ($t(25) = -0.265$, $p = .79$) reported by Kachel et al. [35] in the publication of the scale. This indicates that the baseline gender identity of the women in this experiment is comparable to the baseline gender identity of other women. The median scores for masculine-feminine being (*Mdn* = 5) and masculine-feminine wish (*Mdn* = 5) were identical to the medians for women reported by Tajadura-Jiménez et al. [77], suggesting that the women in both samples were similar in this respect.

*Shape and weight concern.* The average shape concern in the sample was 2.26 (*SD* = 1.71) and the weight concern was 2.03 (*SD* = 1.71). These concerns did not differ significantly from the Australian community norms [56] for shape concerns ($t(25) = 0.087$, $p = .931$) or weight concerns ($t(25) = 0.718$, $p = .479$) of young women. Similarly, the concerns did not differ from the respective community norms in US undergraduate women [46]. Therefore, the body image of the women who participated in this experiment corresponded to existing norms.

*Prior knowledge.* 11 participants reported that they had completed an IAT before taking part in this experiment. 14 participants had heard of the shoe prototype before. Of those, 10 reported to know that the shoes can change body weight perception.

*Emotions*. There were no significant differences in emotional valence ($Z = 1.23$, $p = .22$, $r = .25$), arousal ($Z = 0$, $p = 1$, $r = 0$), or dominance ($Z = -1.48$, $p = .14$, $r = .3$) between the conditions, indicating that people experienced the two walking phases similarly.

*4.3 Summary and limitations of Experiment I – Women*

In summary, the women in this experiment reported to feel lighter, more feminine and potentially weaker after walking with the high frequency step sounds compared to their perception after walking with low frequency step sounds (H1). These findings align with previous work using altered footstep sounds [73, 77] and confirm that the bodily illusion was induced successfully. The self-association of women with ‘male’ and ‘female’ gender categories was not significantly affected by the altered footstep sounds (H2). However, women indicated to feel closer to the group of women after walking with high frequency step sounds compared to the baseline measure (H3). There were no differences in the reported identification with the group of men between the points of measurement (H3). Further, there were no differences in hip or chest movement during the walking conditions. Lastly, the female sample did not differ from comparable women and existing norms in terms of baseline gender identity or shape and weight concerns. However, many participants had relevant prior knowledge about the shoe-prototype.

There were a few limitations of this first experiment which directly informed the conduction of the second experiment and are therefore discussed at this point. During informal chats after the completion of the experiment, several participants mentioned that they did not hear a difference between the high and the low frequency sound condition. Others indicated that while they did hear a difference between the conditions, they focused on for example the background sounds instead of descriptions of the sound itself, such as sounding ‘heavy’ or ‘low’. Therefore, it appeared that there are individual differences in sound perception which should be assessed during the experiment. Furthermore, the experimenter observed that several participants had very small feet, resulting in a poor fit of the sandals. Although participants only completed a short walking phase, their experience is likely to be impeded by the oversized shoes. The analysis of the movement data revealed that many recordings were quite noisy and therefore difficult to interpret. The Notch sensors are relatively new and not all sources of influence could be identified or controlled for. However, smart watches and smartphones were suspected to interfere with the signal and should therefore be turned off or to airplane mode prior to the experiment. Lastly, using a voucher raffle as compensation for the experiment as well as the timing of the experiment in the summer made it difficult to attract many external participants. Recruiting through the personal network resulted in a sample in which many participants knew about the shoe prototype and this prior knowledge might have affected their expectations and experience of the experiment. Therefore, individual monetary compensation should be provided to recruit a better sample.

# 5 Experiment II – Men

### *5.1 Participants*

The second experiment was conducted with 26 cisgender males. The participants had a mean age of 33.62 years (*SD* = 12.87 years). On average, they weighed 74.04 *kg* (*SD* = 10.09 *kg*) and were self-reportedly 178 *cm* (*SD* = 6.2 *cm*) tall. Their average body mass index of 23.7 (*SD* = 2.93) was in the normal range. The eligibility criteria included healthy hearing, no (history of) eating disorders and a shoe size below UK 10 (EU 44) to ensure an acceptable fit of the shoes. 20 participants were native English speakers. Participants were recruited through an online subject pool and the researcher's social network. Each participant was compensated with £7.

The study was approved by the UCL Research Ethics Committee (Project ID: UCLIC/1516/003/ StaffBerthouze/Newbold) and all participants provided written informed consent prior to their participation. The information sheet and consent form are provided in Appendix E.

### *5.2 Method*

The hypotheses for this experiment are identical to the ones formulated for the first experiment with women (Chapter 3). All materials remained the same, however, the order of the IOS scale was swapped, such that the male participants always answered the IOS for the group of men rather than the group of women first. Further, three questions were added at the end of the questionnaire, assessing whether participants heard a difference between the sounds, how they would describe the difference if they heard it and whether their native language is English. The analysis was adjusted to compare baseline gender identity and shape and weight concerns with respective values for the group of men. Specifically, a t-test was calculated to compare the mean TMF scores with the average (*M* = 3) of the reported TMF means for straight men 2.51 (*SD* = 0.98) and for gay men 3.49 (SD = 0.87) by Kachel et al. [35] to account for potential diversity of sexual orientation in the sample. The shape and weight concerns were compared to the respective norms from undergraduate men in the US [40]. Further, there were two minor changes in the experimental protocol. First, before putting on the movement sensors, participants were asked to turn their phones and smartwatches to airplane mode or switch them off completely for the duration of the experiment. Second, participants received as an additional instruction for the walking phase not to turn around at the end of the wooden corridor. Apart from these changes, everything remained identical to the procedure described in Section 3.5.

# 6 Results Experiment II – Men

*6.1 Analysis of the hypotheses*

Bodily feelings Men (H1)

After walking with high frequency step sounds, participants reported to feel significantly more feminine (Z = -2.03, $p < 0.05$, $r = .4$) than after walking with low frequency step sounds. There were no significant differences for light-heavy (Z = -0.99, $p = .322$, $r = .19$) or weak-strong (Z = -0.74, $p = .461$, $r = .14$) perception between high and low frequency step sounds. An overview of the answers to the bodily feelings questions in displayed in Figure 8. The Bayesian analysis reveals weak evidence in favour of the alternative model for femininity-masculinity perception ($B_{10} = 1.56$). Hence, even though there is a tendency for an effect on masculinity-femininity self-perception, there is not enough evidence for a conclusive result. Further, there is anecdotal evidence *against* the alternative hypothesis for light-heavy perception ($B_{01} = 2.23$) and moderate evidence against the alternative hypothesis for weak-strong perception ($B_{01} = 4.53$).

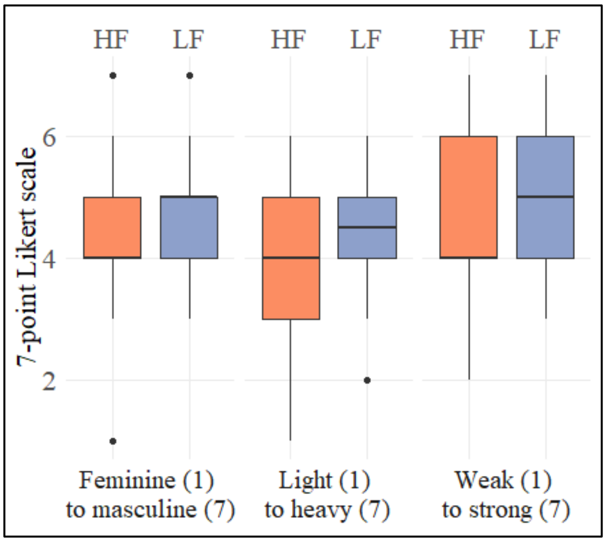


*Figure 8: Answers to the bodily feelings questions on perceived masculinity and femininity, body weight, and strength in the high frequency and low frequency condition.*

Self-gender association (H3)

The IAT scores differed significantly at the three time points ($F(2, 50) = 8.688$, $p < .001$, $\eta^2 = .086$). Participants had significantly higher IAT scores after walking with the high frequency footstep sounds compared to the baseline ($t(25) = -4.02$, $p_{adjusted} < .001$), and compared to the IAT score after walking with low frequency step sounds ($t(25) = 3.27$, $p_{adjusted} < .01$).

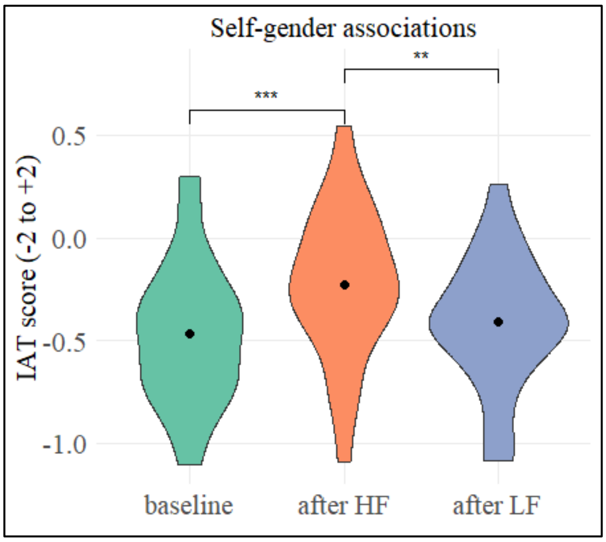


*Figure 9: Distribution of IAT scores (-2 to +2) in the group of Men. The black dot indicates the mean IAT score. A positive score indicates quicker association of 'Self' and 'Female'. A negative IAT score indicates a quicker association of 'Self' and 'Male'*

This finding is supported by the Bayesian analysis with a Bayes factor of $B_{10} = 51.01$ for the overall difference, $B_{10} = 67.26$ for the baseline and high frequency comparison, and $B_{10} = 12.63$ for the comparison between high and low frequency, providing strong evidence for an effect of walking sounds on self-gender association. Thus, participants associated themselves less with 'Male' and more with 'Female' after walking with high frequency step sounds compared to both baseline and low frequency step sounds. The mean and distribution of IAT scores at the three points of measurement are displayed in Figure 9. A detailed overview of the IAT scores for each participant is provided in Appendix C.

<u>Self-gender group relation (H3)</u>

In the baseline measure, men reported to feel closer to the group of men ($M = 5$, $SD = 1.85$) than to the group of women ($M = 3.6$, $SD = 1.55$). The comparison of the values showed that three participants perceived themselves equally close to the group of men as to the group of women. Five participants indicated to feel closer to the group of women than to the group of men.

There was no significant difference in the perceived closeness to the group of women ($\chi^2(2) = 0.839$, $p = .658$) or the group of men ($\chi^2(2) = 2.96$, $p = .228$) between the three points of measurement. No further analysis was performed.

<u>Movement behaviour</u>

Descriptive values for the movement data are displayed in Table 2. There was no significant difference between mean lateral hip sway ($t(25) = 1.88$, $p = .071$) or mean lateral chest sway ($t(25) = -1.92$, $p = .066$) in the high and low frequency condition. The corresponding Bayes factors are $BF_{10} = 0.96$ and $BF_{10} = 1.01$, indicating that in both cases there is not enough evidence to draw conclusions. The maximal lateral hip sway was significantly higher in the low frequency than in high frequency condition ($t(25) = 2.063$, $p < .05$), which is contrary to the expected difference of a higher lateral hip sway in high frequency. No difference was found for maximal chest lateral sway ($t(25) = -1.145$, $p = .263$). The corresponding Bayes factors for maximal lateral hip sway was $BF_{10} = 1.27$ and $BF_{10} = 0.37$ for maximal lateral chest sway. Hence, while there is a tendency supporting the difference in maximal lateral hip sway, there is not enough evidence to draw definitive conclusions. The Bayes factor for maximal lateral chest sway indicates about equal evidence for and against the alternative hypothesis, hence, the available data does not suffice to draw further insights.

*Table 2: Descriptive data of peaks and valleys in lateral hip and chest movement (mean and maximal amplitude, mean number)*

| | **Avg. *M* (*SD*)** | **Avg. *Max* (*SD*)** | **Avg. # of peaks (*SD*)** |
|---|---|---|---|
| Chest high | 6.21 (2.70) | 9.20 (3.51) | 5.58 (0.95) |
| Chest low | 5.71 (2.48) | 8.72 (3.15) | 5.42 (0.81) |
| Hip high | 6.61 (2.72) | 9.54 (3.55) | 6.00 (1.06) |
| Hip low | 7.03 (2.17) | 10.3 (3.27) | 5.75 (1.11) |

### *6.2 Influencing factors*

The purpose of the following section is (I) to assess whether the gender identity, shape and weight concerns of the sample were comparable to available community norms, hence, whether the findings are likely to apply to other men as well, and (II) to provide more information prior knowledge, the experience and interpretation of the altered footstep sounds as an indicator whether participants were conscious of the true purpose of the experiment when answering the self-report questions.

*Baseline gender identity.* The mean TMF score for male participants was 2.7 (*SD* = 1.1) and did not differ from the mean of the two scores for gay and straight men ($t(25) = -1.54$, $p = .135$) reported by Kachel et al. [35], indicating that the baseline gender identity of the men in this experiment was comparable to the baseline gender identity of other men. The median scores for masculine-feminine being (*Mdn* = 2.5) and for masculine-feminine wish (*Mdn* = 2) were slightly higher than the respective medians for the male participants in the sample of Tajadura-Jiménez et al. [77].

*Shape and weight concern.* The mean shape concern in the male sample was 1.43 (*SD* = 1.2) and the mean weight concern was 1.36 (*SD* = 1.3). These concerns did not differ significantly from the US community norms for shape concerns ($t(25) = -0.67$, $p = .508$) or weight concerns ($t(25) = 0.28$, $p = .781$) of young men [40]. Therefore, the body image of the men who participated in this experiment corresponded to existing norms.

*Prior knowledge.* 11 participants reported that they had completed an IAT prior to taking part in the experiment. 2 participants had heard of the shoe prototype before but neither of these knew that they could be used to changes body weight perception.

*Emotions*. There were no significant differences in valence ($Z = -0.637$, $p = .542$, $r = .12$), arousal ($Z = -0.937$, $p = .349$, $r = 0.18$), and dominance ($Z = -0.217$, $p = .828$, $r = 0.04$) between the low and high frequency step sounds.

*Hypothesis.* 10 participants related the footstep sounds to perceived masculinity, femininity or gender identity. 2 participants included the perception of other individuals in their explanation.

*Sound perception.* 20 participants reported to have noticed a difference between the sound conditions. Of these, 6 participants described the difference in terms of light or heavy sounds. Other descriptions referred to the type of shoes (*e.g.*, high heels, boots), the material of the ground (*e.g.*, wood, stone), other features of the sounds (*e.g.*, volume, sharpness) or emotional connotations (*e.g.*, calm, stressing).

### *6.3 Summary of Experiment II – Men*

In summary, the men in this experiment reported to feel more feminine after walking with the high frequency step sounds compared to their perception after walking with low frequency step sounds (H1). Deviating from prior work using altered footstep sounds [73, 77], no differences in their reported weight or strength perception were found (H1). Further, there were no differences in the reported identification with the group of women or with the group of men between the points of measurement (H2). However, the self-association of men with ‘male’ and ‘female’ gender categories differed significantly between the conditions. Men associated themselves relatively stronger with ‘female’ after walking with high frequency step sounds compared to the baseline measure and compared to their associations after walking with low frequency step sounds (H3). Lastly, the male sample did not differ from comparable men and existing norms in terms of baseline gender identity and shape or weight concerns.

# 7 Combined analysis

Although previous work did not find differences in sound perception based on sex [77], the results from the two presented experiments in this thesis suggest slight differences between the male and female participants. For the women in Experiment I, altered footstep sounds affected perceived masculinity and femininity, body weight and strength as well as self-identification with the group of women, but not self-association with gender categories. Instead, for the men in Experiment II, altered footstep sounds affected self-association with gender categories and perceived masculinity and femininity, but not perceived body weight and strength or identification with gender groups. Thus, a combined analysis of the two datasets would be interesting as it allows to explore potential interactions between the effect of the sound conditions and the sex of the participant. Although the materials and procedure of the two experiments were almost identical (see Section 5.2), the small differences might have affected the participant’s experience and responses. Also, there were differences between the male and female sample, for example regarding the age distribution and number of native speakers, which arose partially from the different monetary compensation in the second experiment. Therefore, this combined analysis should be understood as an explorative supplement to previous analyses.

Measurement

The ordinal data from the bodily-feelings questions and IOS scale does not fulfil the criteria for a mixed two-way ANOVA with sex as a between factor and condition as a within factor. However, as the non-parametric Friedman test for repeated measures which was used for previous analyses is not suitable for analysing mixed factor designs, the data was ‘aligned rank transformed’ with the ARTool package (v. 0.10.6) in R [38], which allows a consecutive analysis with a two-way mixed ANOVA [32]. The IAT data was not transformed and also analysed with a two-way mixed ANOVA. Significant main effects were interpreted based on the interaction plots (Appendix D) and for the IOS and IAT data, a contrast analysis as described by Kay [37] was performed with the eemeans package (v. 1.4.2) [43] in R.

Bodily feelings (H1)

For the light-heavy perception, there was a significant main effect of sound condition ($F(1,49) = 5.84$, $p < .05$), with participants feeling heavier after walking with the low frequency footstep sounds. Neither the main effect of sex ($F(1,49) = 0.57$, $p = .454$) nor the interaction between sex and sound condition ($F(1,49) = 1.04$, $p = .313$) were significant.

For the weak-strong perception, there was a significant main effect of sound condition ($F(1,49) = 4.16$, $p < .05$), with participants feeling stronger after walking with the low frequency footstep sounds. Neither the main effect of sex ($F(1,49) = 1.1$, $p = .3$) nor the interaction between sex and sound condition ($F(1,49) = 1.74$, $p = .194$) were significant.

For the masculine-feminine perception, there was a significant main effect of sound condition ($F(1,49) = 25.48$, $p < .001$), with participants feeling more masculine after walking with the low frequency footstep sounds. The main effect of sex was also significant ($F(1, 49) = 9.1$, $p < .01$) with women indicating to feel more feminine than men on average. The interaction between sex and sound condition failed to reach significance ($F(1, 49) = 3.49$, $p = .068$).

Self-gender association (H2)
For the IAT scores, the main effect of sound condition was significant ($F(2,100) = 5.74$, $p < .01$). As expected, the main effect of sex was also significant ($F(1,50) = 23.411$, $p < .001$), with women having stronger self-female associations (higher IAT scores) than men. There was no significant interaction between sex and sound condition ($F(2,100) = 2.21$, $p = .115$). The contrast analysis and visual inspection of the combined data in Figure 10 revealed a significantly stronger self-female association after walking with high frequency step sounds compared to the baseline measure ($t(100) = -3.19$, $p < .01$). The difference between the IAT scores after walking with high and with low frequency failed to reach significance ($t(100) = 2.263$, $p = .066$).

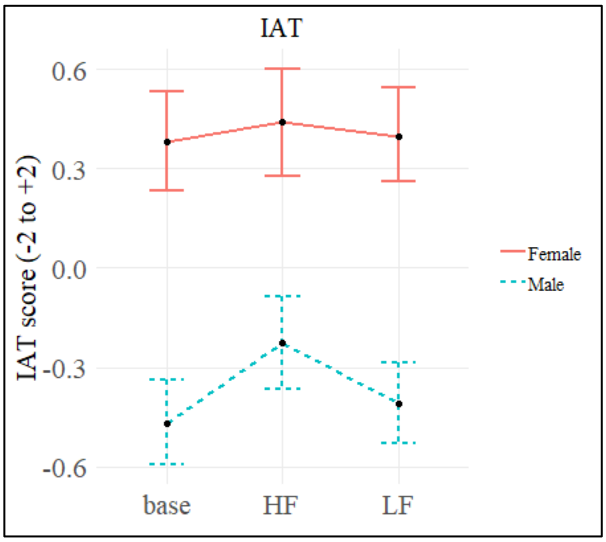


*Figure 10: Mean IAT scores for male and female participants. Error bars show confidence intervals.*

Self-gender group identification (H3)
In the IOS scores measuring the relationship with the group of women the main effect of sound condition was significant ($F(2, 98) = 3.24$, $p < .05$). As expected, the main effect of sex was significant as well ($F(1, 49) = 23.24$, $p < .001$), with the female participants generally indicating to feel closer to the group of women compared to the male participants. The interaction between sex and sound condition was not significant ($F(2, 98) = 0.48$, $p = .618$).

Neither of the contrasts reached significance. One reason for that could be that the answer patterns differed between male and female participants (Figure 11) and overall variation in the IOS scores across conditions was small. Different from the expected effect, Figure 11 shows that male participants indicated to feel relatively closer to the group of women after walking with low frequency step sounds. Unlike in the analysis of the Experiment I (Section 4.1), the difference between the baseline IOS score and the IOS score after walking with high frequency sounds failed to reach significance ($t(98) = -2.144$, $p = .086$), hence, the participants did not feel significantly closer to the group of women after walking with the high frequency step sounds.

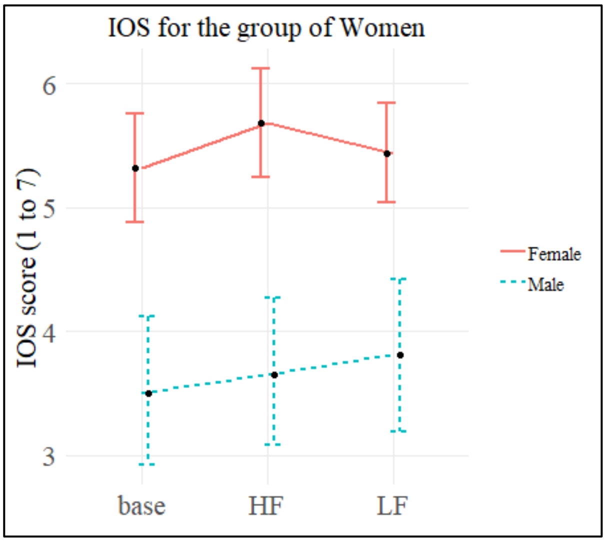


*Figure 11: Mean IOS scores at the three points of measurements for male and female participants. Error bars show confidence intervals.*

For the IOS measuring the relationship with the group of men, the main effect of sex was significant ($F(1,49) = 9.1$, $p < .01$) with male participants indicating to feel closer to the group of men compared to female participants. Neither the main effect of sound condition ($F(2,98) = 1.48$, $p < .232$) nor the interaction between sex and sound condition ($F(2,98) = 0.77$, $p = .461$) were significant. Hence, no contrast analysis was performed.

<u>Summary</u>

Overall, the combined analysis of the data supports the findings from Experiment I and II that walking with altered footstep sounds affects bodily feelings (H1) and the self-association with male and female gender categories (H2). Further, the results suggest that these effects do not interact with the participant's sex and that the differences in the results of Experiment I and II could be due to the sample size. As expected, men and women differed in their overall perceived masculinity and femininity, identification with gender groups and self-association with 'male' and 'female' gender categories. The findings for the self-identification with gender groups (H3) in the combined sample are less clear and they partially differ from the results in Experiment I and II. Further, the IOS scores are the only measure in which the tendencies of the responses from male and female participants diverge (Figure 11). For all other measures, the answer patterns across conditions are similar between the two samples (see Figure 10 and Appendix D). The IOS scale and the findings from the two experiments are discussed in Chapter 8.

# 8 Discussion

The experiments described in this thesis investigated whether altering footstep sounds in real-time can affect the perceived masculinity and femininity, the self-association with ‘male’ and ‘female’ gender categories, and the relation to the social groups of the walker. Previous work suggests that social cognition could be connected to physical experiences, as body swap illusions have been shown to decrease implicit biases towards the embodied group [47, 61]. Two recent reviews theorize that this connection between implicit attitudes and body swap illusions results from a change in the perception of one’s own body and one’s self-concept [48, 80]. Thus far, only two experiments directly address changes in the self-concept following body swap illusions [3, 72]. Neither of these studies investigated the effect of more subtle changes in one’s *own* body perception as opposed to the effects of embodying someone else’s body. Furthermore, most research investigated attitudes towards *racial* outgroups and visual-tactile (*e.g.*, a RHI with dark skinned rubber hand [22]) or visuo-proprioceptive (*e.g.*, embodying an avatar with dark skin colour in VR [61]) sensory modalities to induce bodily illusions. This thesis adds to these four areas of research by (I) focusing on changes in the self-concept instead of implicit attitudes towards others, (II) investigating illusions of one’s own body instead of body swap illusions, (III) investigating gender identity instead of race, and by (IV) using auditory sensory information to induce a bodily illusion.

In two experiments with cisgender females and males, I replicated the finding that footstep sounds affect perceived masculinity and femininity during walking [77], suggesting that auditory feedback can induce a temporary ‘gender illusion’ (H1). Further, the results provide evidence for a connection between body perception and self-identification with social groups, as women (Experiment I) reported to feel closer to the group of women after walking with high frequency footstep sounds (H3). Moreover, men (Experiment II) associated themselves relatively stronger with ‘female’ gender categories after walking with high frequency footstep sounds and stronger with ‘male’ after walking with low frequency footstep sounds. This difference indicates a temporary change in the self-concept induced through altered footstep sounds (H2).

Taken together, my findings support the theory by Maister et al. [48] and Tsakiris et al. [80] that bodily illusions affect social cognition through changes in the self-concept. According to their theory, the bodily illusion causes the inclusion of features of the embodied group in the self-concept. The results from the two groups of participants contribute to this theory differently. The IAT responses in the male sample (Experiment II) indicate a comparably stronger self-female association after walking with high frequency footstep sounds. This suggests that experiencing the bodily ‘gender illusion’ caused male participants to incorporate more features of females into their self-concept, increasing the perceived similarity between the self and females. According to the theory [48, 80], the increased perceived similarity strengthens the self-association of men with females which becomes visible in the change in the IAT score. Furthermore, The IOS responses in the female sample (Experiment I) suggest that the bodily illusion caused an increased overlap of the mental representation of the self and the embodied group, as women indicated themselves to be closer to the group of women after walking with high frequency step sounds.

However, contrary to one of my hypotheses, the self-association of women (Experiment I) with ‘male’ and ‘female’ gender categories was not affected by the footstep sounds (H2). There are several possibilities why the effect was found in the male sample but not in the female sample. Firstly, the frequency components in the footstep sounds are not only indicators for the sex, but also for the body weight of the walker [44], and have been shown to affect body weight perception in previous experiments [73, 77]. As the shape and weight concerns are generally higher among females compared to men, and several participants knew about the effect of footstep sounds on body weight perception, the women might have interpreted the sounds more strongly in relation to body weight than in relation to sex. This possible explanation is supported by the self-report questions on bodily feelings, where women indicated to feel heavier and lighter in the respective sound conditions, while there was no such effect for men (H1). Secondly, only six women originated from countries where English is the primary language while most (20 of 26) men indicated that English is their native language. If the participants did not mentally refer to themselves in English terms, the IAT potentially failed to capture self-association and hence, failed to reveal a change in self-concept. Lastly, women possibly wear a wider range of shoe types in their everyday life (*e.g.*, heels, boots, sneakers) and might therefore be more familiar with alternating sounds of their footsteps. Therefore, they potentially associated the different sounds stronger with alternating footwear instead of with sex. Hence, the way females interpret high and low frequency footstep sounds should be explored further.

Diverging from the findings in the first experiment and the formulated expectations, I found no effect of footstep sounds on self-gender group relation for the male participants (H3). This is surprising given that both the findings in the self-gender IAT (H2) and the self-reported masculinity-femininity perception (H1) indicate a change in gender perception which is expected to affect gender group identification as well. One explanation for this could be that the participants misinterpreted the IOS scale to target *attraction* towards rather than identification with the respective gender group. This explanation is based on observed mismatches between the answers to the TMF scale and the IOS scales for some of the participants. For example, a participant would indicate to be very masculine in the TMF scale but then choose distant circles in the IOS for the group of men and the closest circles in the IOS for the group of women (*i.e.*, completely overlapping circles). Therefore, the IOS scale might have failed to capture participant's identification with the gender groups. For future applications of this scale, the aim of the question should be clarified in the instructions. Additionally to potential misinterpretation of the question, as the IOS is a self-report measure, participants might have not reported small differences in self-perception because they were not consciously aware of such changes [4]. The IOS scale has previously been used to assess perceived closeness with the embodied individual but not with the general group represented during the bodily illusion [59]. Given that the variation of IOS scores across conditions was relatively small, participants might have made a reflected decision on how they relate to the respective groups in the beginning of the experiment and consequently chose the same options again without reflecting on their immediate experience. One option to overcome this effect could be to provide a continuous scale on which participants can manually adjust the distance of the circles to their perception.

In the participant movement data, as collected using the Notch sensors, no differences in gait were found in mean lateral hip and chest sway between the two sound conditions. Although it is certainly possible that there were no differences in gait, I will briefly discuss factors that might have prevented the discovery of such differences. The available walking corridor was very short and therefore, only a few steps could be extracted from each participant. These might not reflect natural gait and might be too few to reveal differences between the conditions. Furthermore, the sensor recordings were partially noisy which complicated the identification of peaks and valleys, and the analysis of the data. Also, the Notch sensors have, to my knowledge, not yet been used to analyse differences in masculine and feminine gait. While the analysis is based on existing work with other sensors [79] and the trial recordings of mimicked masculine and feminine gait showed the expected differences in lateral hip and chest tilt (Appendix A), the chosen sensors might have failed to identify more subtle differences in the gait of the participants. Apart from lateral hip and chest tilt, there could be other factors that are indicative of masculine and feminine gait (*e.g.*, rotation phase of shoulders and hips, distance between shoulders and hips) that would have revealed a difference. However, the collection and analysis of movement data was not the priority of this thesis. Future work in this direction should first evaluate and compare measurements of feminine and masculine gait when using the Notch sensors to identify all relevant features for discrimination. When collecting new data, a sufficiently long walking corridor should be provided, signal interferences should be further minimised (*e.g.*, no unnecessary electronic devices or metal objects in the same room), and participants could be asked to wear thin and tight clothing to ensure a good fit of the sensors.

Implications for theory

In the previous section, I explained how the findings of this thesis relate to the theory of Maister et al. [48] and Tsakiris et al. [80] on the connection between bodily illusions and social cognition. Additionally, there are a few general theoretical implications of my work which I will discuss in this section. I will also connect my work to embodied cognition and point out some future directions for research.

The IAT findings of this experiment provide evidence for a connection between physiological experiences and higher-level cognition. The IAT which I used for this experiment measured self-gender association based on the speed of associating terms describing 'self' and 'other' with terms describing 'male' and 'female'. Hence, this IAT assessed a more abstract conceptualisation of the self, *i.e.* semantic descriptions of oneself and social gender groups. The observed change in this association shows that the bodily illusion did not only affect participant's physical self-perception but also their higher-level conceptual self. This is different from previous work on changes in the self-concept, as previous work assessed changes in implicit associations with the sensory features that were manipulated during the bodily illusion. For example, Banakou et al. [3] and Tajadura-Jiménez et al. [72] altered the physical appearance of participants by inducing a body ownership illusion of a child avatar in VR and used an IAT with *images* of adults and children to measure self-association with adults and children. If it is the case that bodily illusions change the self-concept by increasing self-associations with the embodied group and decrease the perceived difference between one's in- and outgroup [48, 80], then this change in self-concept should become apparent independently of the sensory modality used to induce the change in self-concept. The experiments presented in this thesis show that auditory bodily illusions can cause changes in self-perception beyond the sensory information that is altered during the illusion.

Although IATs have been used to measure aspects of the self-concept and identity, the IAT employed in this experiment likely only captured a small facet of the self-concept of the participants. Differences across research projects in defining and assessing the self-concept, as well as ambiguous use of terminology to describe the physical and conceptual aspects of the self, pose challenges for relating the experimental findings to different levels of human cognition. For example, in the line of research investigating the effect of embodying another face (enfacement illusions) on self-recognition, recognizing a face as one's own is described to be closely related to our identity, "*The face holds a special importance for our sense of identity because it is the most distinctive feature of our physical appearance.*" (p. 262, [63]). However, in order to understand the effect of bodily illusions on our self-concept and social relationships, physical resemblance is only the first step [48, 80] and it is important to distinguish it from changes in higher-level cognition and a more abstract sense of self-identity. The observed change of responses in the self-gender IAT, which was employed in these experiments, is a good first indicator for a change in self-associations. However, it remains unclear how meaningful these observed changes of self-associations in an IAT are for our higher-level self-concept and for our behaviour. Therefore, future experiments should also consider alternative methods to assess the effect of bodily illusions on the self-concept and relation to social groups. For example, assessing whether a bodily illusion can improve pain recognition in the embodied group due to an increased outgroup identification (see [86]), or whether brain regions that are connected to the self-concept show changes in activity in response to bodily illusions (see [21]).

The finding that alterations in body perception connect to the self-concept and in- and outgroup identification also supports a grounded or embodied approach to human cognition. This approach assumes that our higher-level cognition is grounded in multimodal sensory experiences. Therefore, considerable attention is paid to physical sensations and the relationship between the body and the brain [7]; exploring for example the influence of fluid movements on creativity [69] or of motor cues on social judgements [70]. In the context of bodily illusions, previous research on body swap illusions found that embodying an Albert Einstein avatar can enhance performance in a cognitive task [5] and that gender swap illusions can improve performance in stereotype threatening situations [60]. Here, I add to this line of research by showing that subtle alterations of the sensory experience of one's *own* body connects to higher-level cognitive processes, such as the perception of the self and identification with gender groups. Based on these induced changes in the self-concept, it would be interesting to investigate whether such subtle illusions of one's own body can cause changes beyond the self-concept, for example alter one's performance in stereotype threatening situations or one's implicit attitudes towards others.

Empirical results, as the one presented in this thesis, are also important to develop new and validate existing cognitive models. Cognitive models can be an important method to investigate the underlying cognitive processes of the connection between bodily illusions and higher-level cognition. For example, Bedder et al. [8] modelled the effect of bodily illusions on self-perception and the subsequent response behaviour in an IAT for racial biases. Their simulated IAT responses closely resembled observed human IAT responses after experiencing bodily illusions, suggesting that their proposed 'self-image' network model could be a first step to describe the cognitive processes underlying the connection between bodily illusions and social cognition. The data set collected in this thesis could contribute to the development and validation of this and other cognitive models, and eventually aid our understanding of human cognition.

<u>Implications for practice</u>

Besides the theoretical implications, the findings of this thesis are also relevant for a number of practical applications. First, I will relate the findings to the field of Artificial Intelligence, as this thesis was conducted as part of an Artificial Intelligence Research Master. Then, I will discuss the implications of the findings for different applications of auditory feedback.

The findings on gender identity and its malleability have implications for developments in the field of Artificial Intelligence (AI). AI algorithms are frequently deployed for gender classification, for example based on the analysis of gait data [87] or facial features [68]. These systems typically adopt a binary perspective of gender identity, focus on visible features, and consider gender identity to be static [65]. If such classifications inform other systems, decisions, and recommendations, misclassification could lead to harmful consequences for individuals and foster gender-based stereotypes. Challenging this 'AI view of gender identity', our baseline measures show that self-identified cisgender males and females adopt a more nuanced view of gender identity and rarely classify themselves as 'very feminine' or 'very masculine'. Instead, participants identified themselves with aspects of both male and female gender, supporting the understanding of gender identity as a spectrum [34] rather than distinct binary categories. Furthermore, the findings provide evidence that perceived masculinity, femininity, and gender identification can be temporarily influenced through subtle interventions and without any visible indications of a change. Such subtle variations of footstep sounds could potentially also be induced in everyday life, for example when wearing new shoes, and cannot be accounted for with existing AI classifiers.

The finding that subtle alterations of footstep sounds can affect one's self-perception allows us to consider real-life applications of bodily illusion experiences. Previously, such illusions were mostly induced with visual and tactile sensory information, for example when embodying an avatar in a VR environment [45, 60]. While creating such experiences in VR requires a comparably complex setup, this thesis showed that real-time auditory feedback can induce similar illusions using a more straightforward approach. As headphones are frequently worn by many people in their daily life, a system altering footstep sounds could be integrated in everyday tasks and experiences. Auditory feedback has different potential applications. Altering footstep sounds in real-time, as with the shoe-prototype used in this experiment, has already been shown to change body weight perception, bodily feelings, and gait, which could facilitate physical activity [73, 77]. The findings in this thesis contribute to the design of effective physical activity support systems, by showing that in addition to weight perception, high and low frequency step sounds can also affect perceived masculinity and femininity, and one's association with male and female gender groups. This might be relevant to obtain a better understanding of the effects of real-time auditory feedback on the user and improve the tailoring of such systems to individuals. In addition, the findings also inspire new applications of auditory feedback. For example, real-time alteration of footstep sounds could potentially be employed for training purposes in the context of gender discrimination. Specifically, by using feminine or masculine sounding footstep sounds it is possible to temporarily increase or decrease one's identification with gender in- and outgroups. Identification is considered to be an important factor for addressing prejudice and discrimination [29]. Further, a technology that allows alteration of footstep sounds in real-time could also be used for the exploration of one's own masculinity and femininity, for example for individuals who are transgender or gender fluid.

# 9 Conclusion

Bodily illusions have been frequently used for two different research purposes: (I) to study multisensory integration and changes in self- and body representation, and (II) to explore the effect of owning an outgroup's body on implicit attitudes and social cognition. In line with these two areas of research, this thesis focused on changing the perception of one's *own* body through auditory feedback rather than inducing the illusion of owning another body, and on measuring the effect of such an illusion on changes in the self-concept and identification with social groups rather than implicit attitudes towards others.

In two experiments with cisgender males and females, I show that subtle alterations of footstep sounds can affect perceived femininity and masculinity, self-association with male and female gender, and identification with gender groups of the walker. After walking with high frequency (feminine sounding) footstep sounds, both men and women perceive themselves to be more feminine, women perceive themselves to be closer to the group of women, and men associate themselves relatively stronger with the female gender. These findings suggest that gender identity is temporarily malleable through sensory experiences and that body perception is linked to higher-level cognition, such as the self-concept and relation to social groups.

My work contributes to the scientific understanding of illusions of one's own body (as opposed to body swap illusions) and the effect of such illusions on the self-concept and relation to social groups. The findings support the theory that the connection between body swap illusions and implicit attitudes towards others occurs through a change in one's own body perception and one's self-concept.

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# APPENDIX

### A – Additional material (Movement analysis)

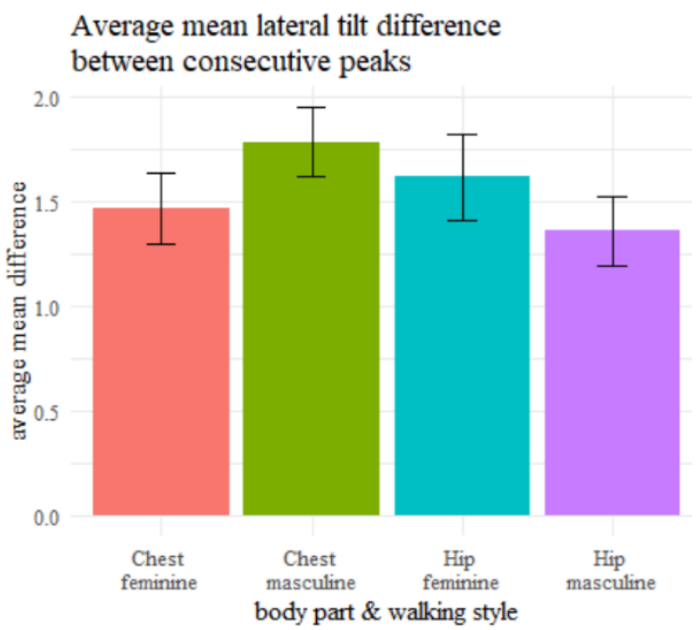


*Figure A.1: Overview of the results from the trial recordings of masculine and feminine gait with the Notch movement sensors. The plot shows the expected differences of higher lateral chest movement in the 'masculine walking' and higher lateral hip tilt in the 'feminine walking' compared to the respective other condition.*

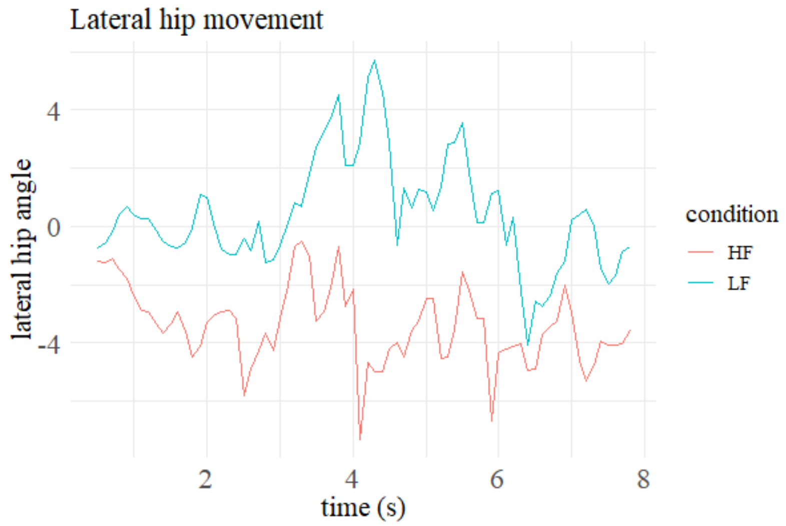


*Figure A.2: Example plot of movement data in which peaks could not be clearly identified.*

**B – Additional material (Experiment I Women)**

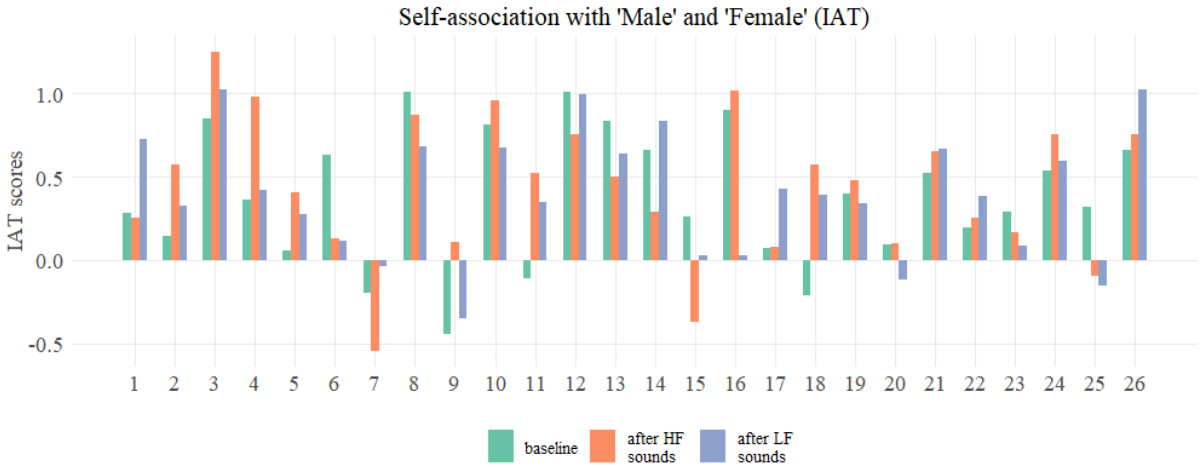


*Figure B.1: Overview of IAT scores (-2 to +2) at the three points of measurement for all 26 female participants. A positive IAT score indicates a stronger self-female association. For the expected pattern (e.g., participant 2,3, and 4), the IAT score after the high frequency condition (orange) is higher than baseline the low frequency condition (green and blue).*

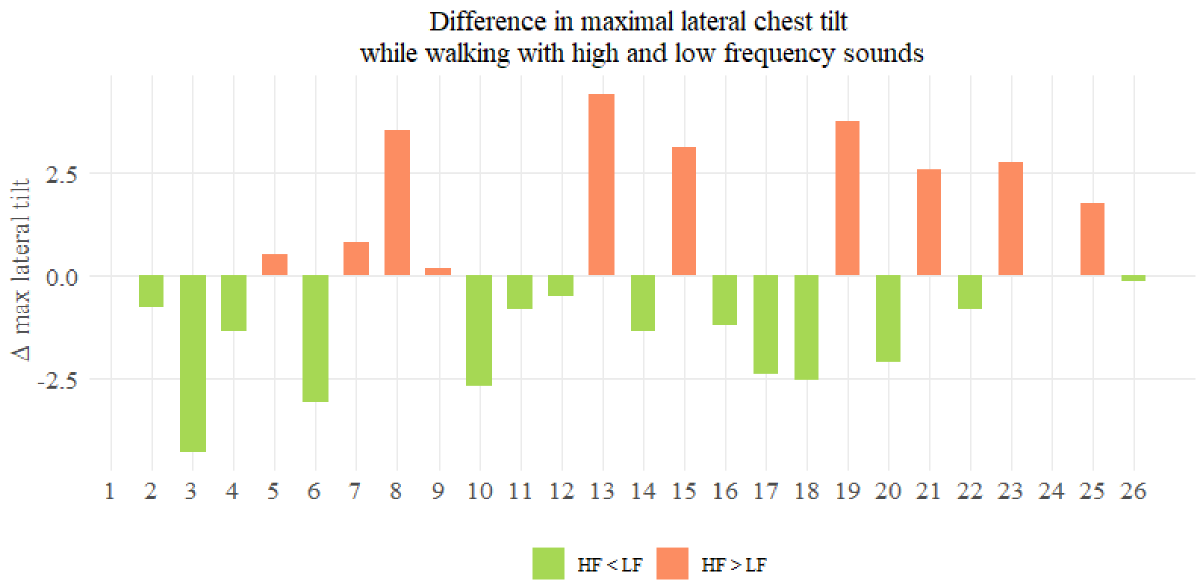


*Figure B.2: Comparison of maximal lateral chest tilt in walking with high and low frequency sounds. If there was less maximal lateral chest tilt in the high frequency condition than in the low frequency condition, the bars are green (expected difference), otherwise they are red (unexpected difference).*

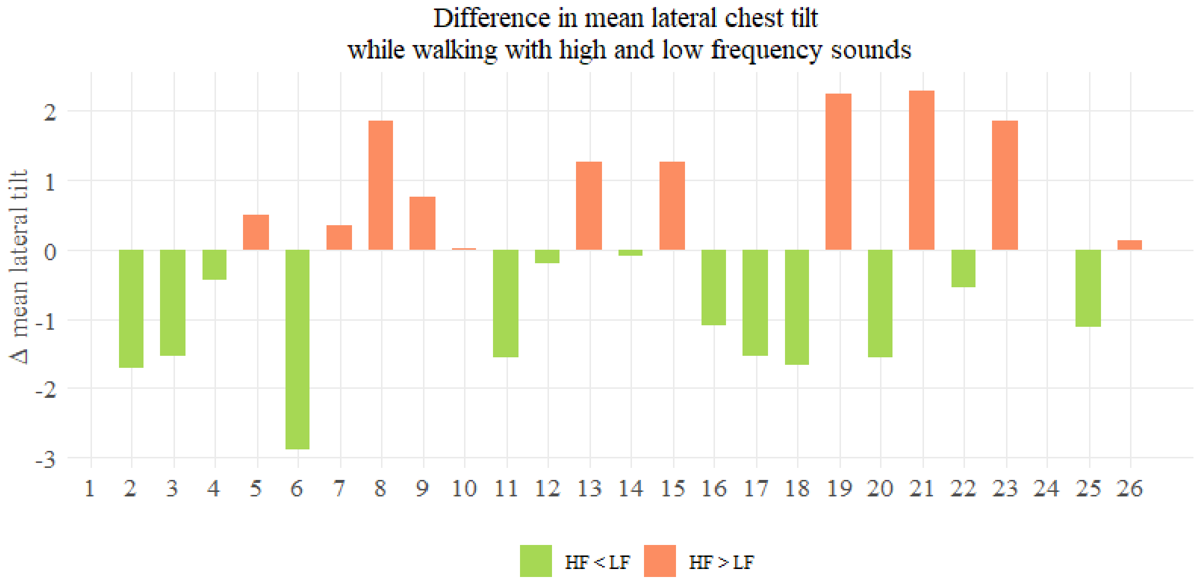


*Figure B.3: Comparison of average lateral chest tilt in walking with high and low frequency sounds. If there was less maximal lateral chest tilt in the high frequency condition than in the low frequency condition, the bars are green (expected difference), otherwise they are red (unexpected difference).*

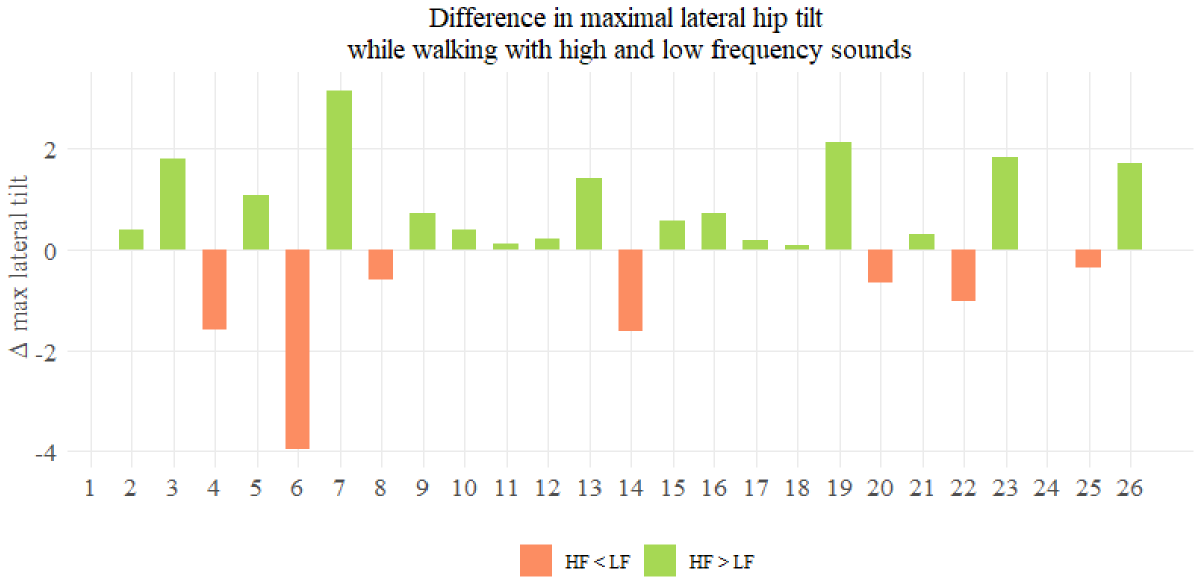


*Figure B.3: Comparison of maximal lateral hip tilt in walking with high and low frequency sounds. If there was more maximal lateral hip tilt in the high frequency condition than in the low frequency condition, the bars are green (expected difference), otherwise they are red (unexpected difference).*

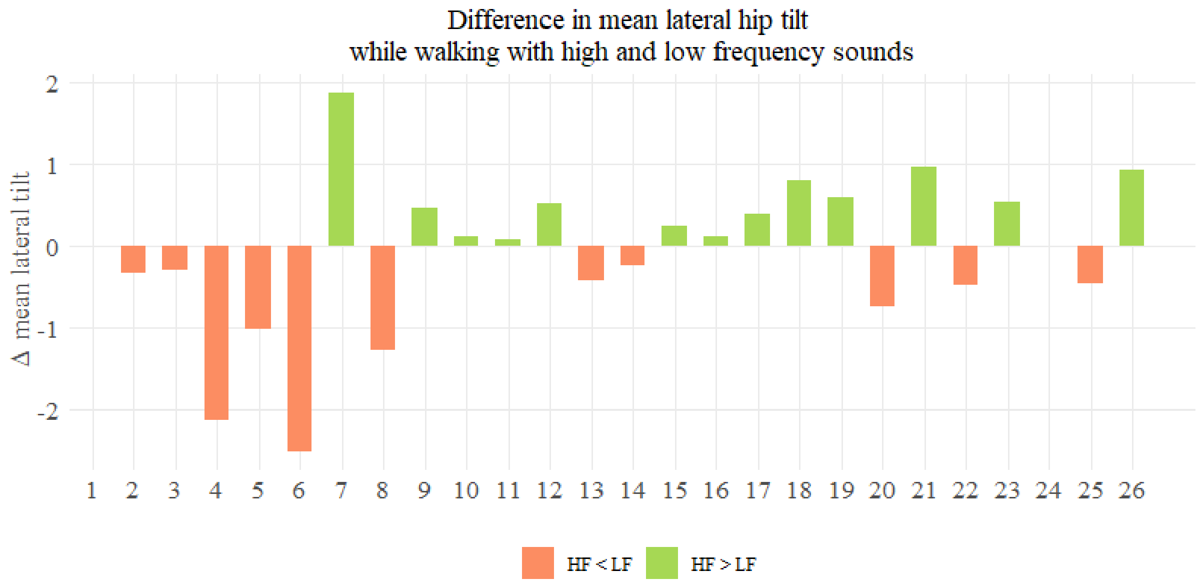


*Figure B.4: Comparison of average lateral hip tilt in walking with high and low frequency sounds. If there was more maximal lateral hip tilt in the high frequency condition than in the low frequency condition, the bars are green (expected difference), otherwise they are red (unexpected difference).*

**C – Additional material (Experiment II Men)**

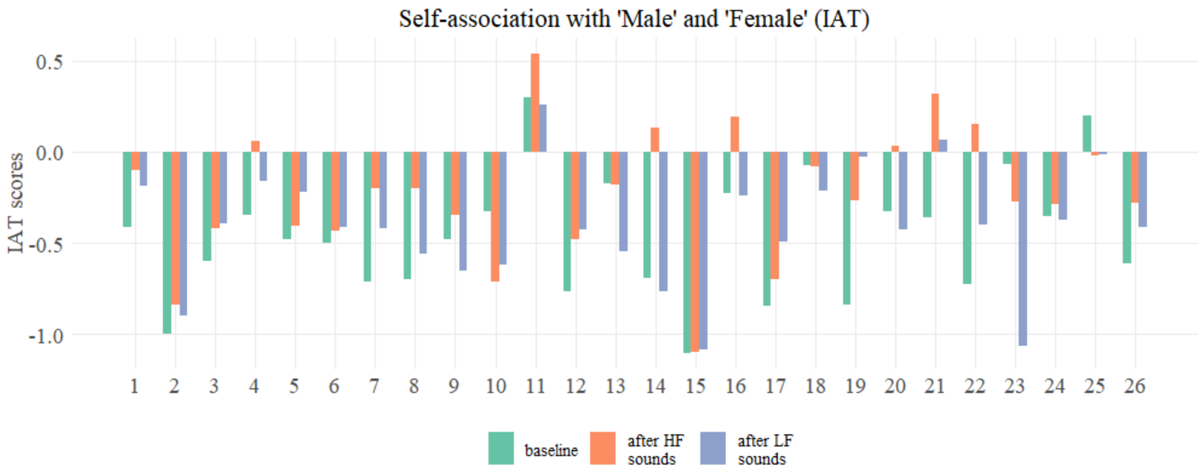


*Figure C.1: Overview of IAT scores (-2 to +2) at the three points of measurement for all 26 male participants. A negative IAT score indicates a stronger self-male association. For the expected pattern (e.g., participant 4,9, and 11), the IAT score after the high frequency condition (orange) is higher than baseline the low frequency condition*

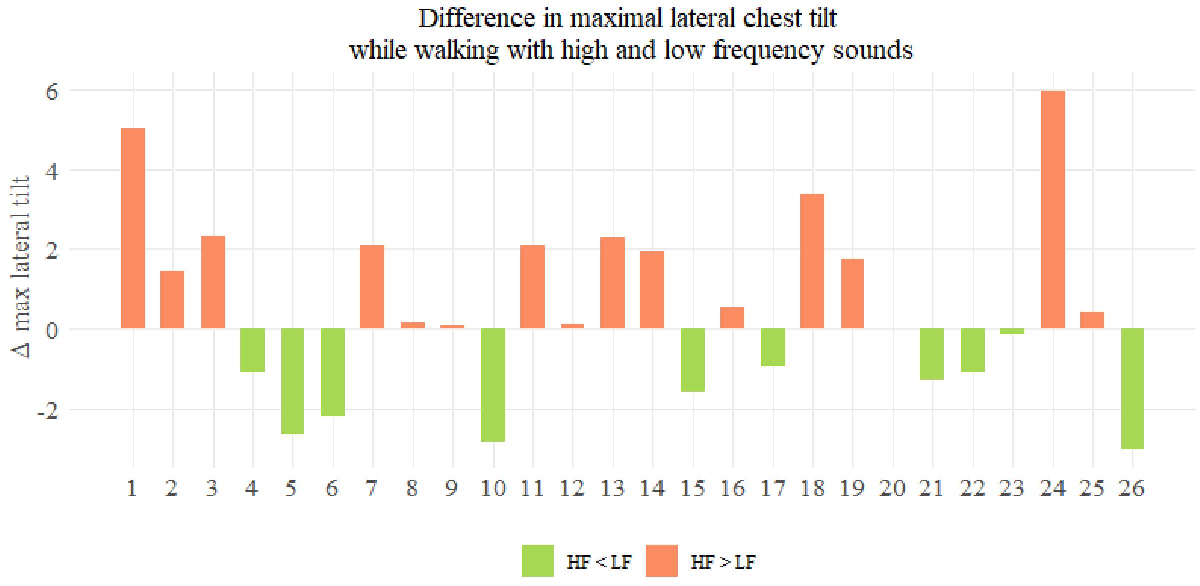


*Figure C.2: Comparison of maximal lateral chest tilt in walking with high and low frequency sounds. If there was less maximal lateral chest tilt in the high frequency condition than in the low frequency condition, the bars are green (expected difference), otherwise the bars are red (unexpected difference).*

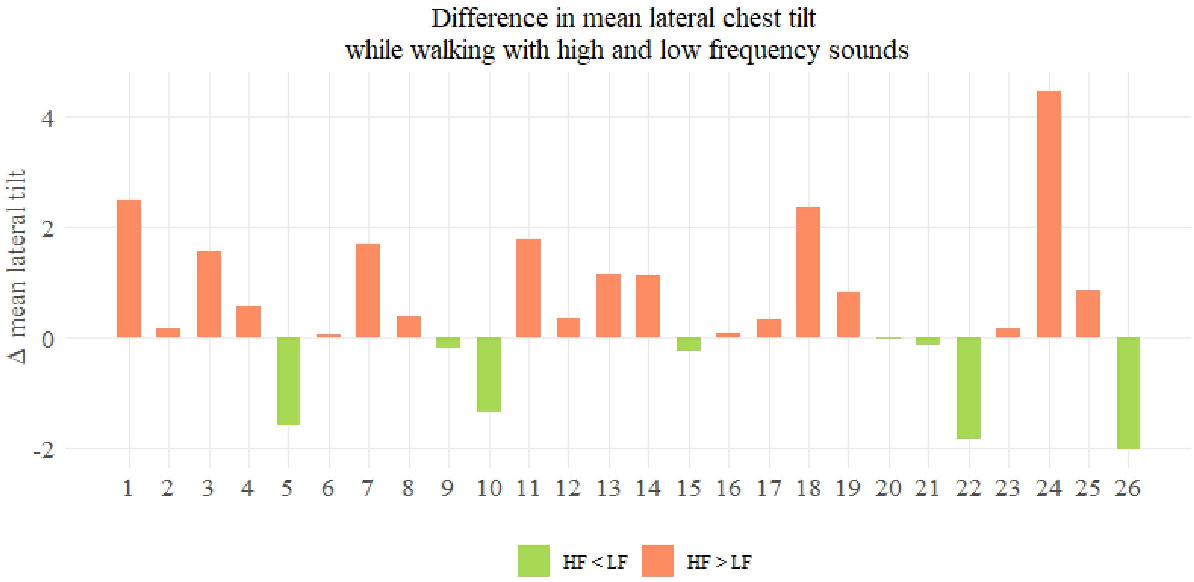


*Figure C.3: Comparison of average lateral chest tilt in walking with high and low frequency sounds. If there was less average lateral chest tilt in the high frequency condition than in the low frequency condition, the bars are green (expected difference), otherwise the bars are red (unexpected difference).*

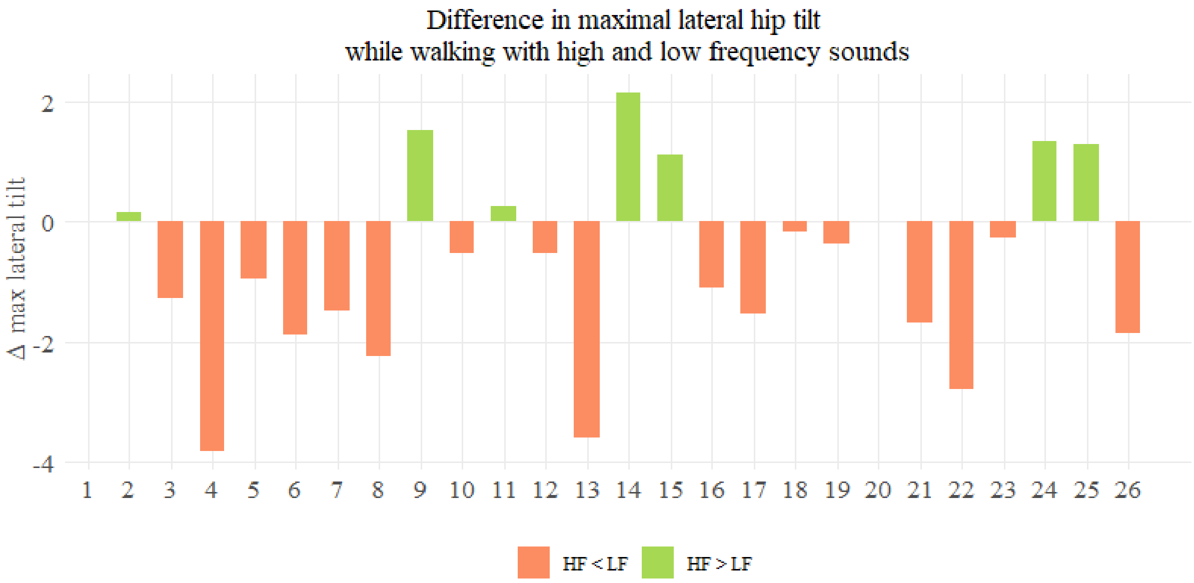


*Figure C.4: Comparison of maximal lateral hip tilt in walking with high and low frequency sounds. If there was more maximal lateral hip tilt in the high frequency condition than in the low frequency condition, the bars are green (expected difference), otherwise the bars are red (unexpected difference).*

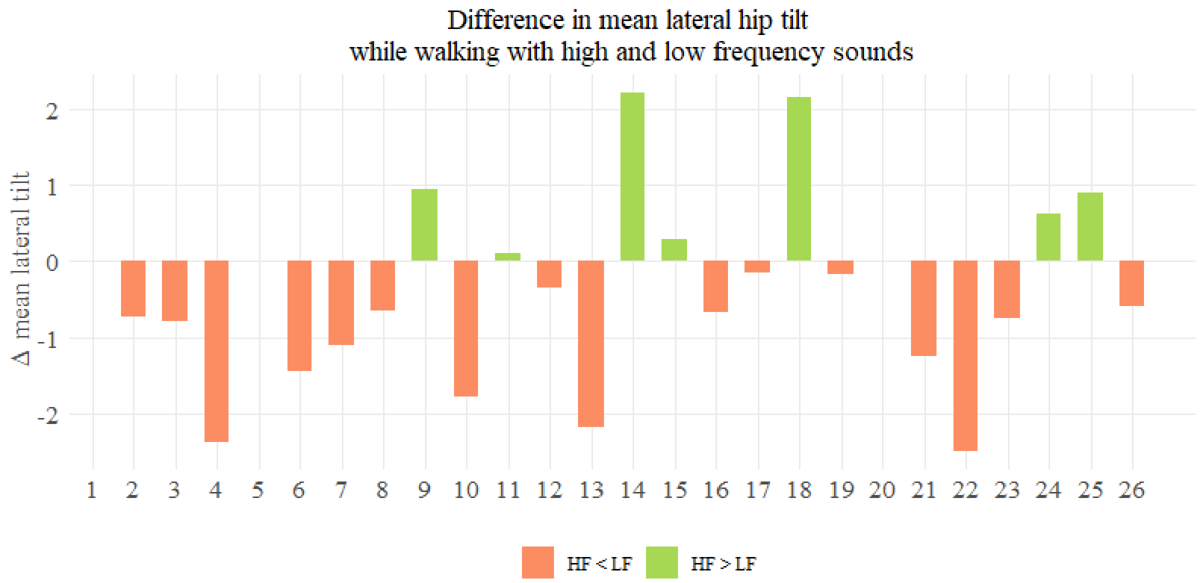


*Figure C.5: Comparison of average lateral hip tilt in walking with high and low frequency sounds. If there was more average lateral hip tilt in the high frequency condition than in the low frequency condition, the bars are green (expected difference), otherwise the bars are red (unexpected difference).*

**D – Additional material (Combined Analysis)**

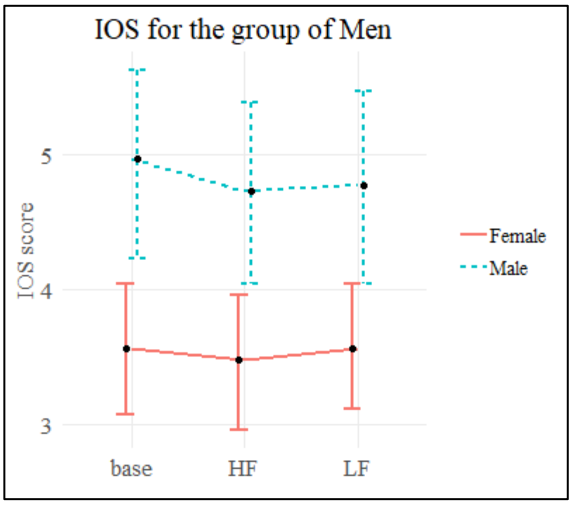


*Figure D.1: IOS scores for the relationship to the group of men for male and female participants. A higher score equals a closer relationship between self and the group of men. Black dots represent the mean IOS score and error bars represent confidence intervals.*

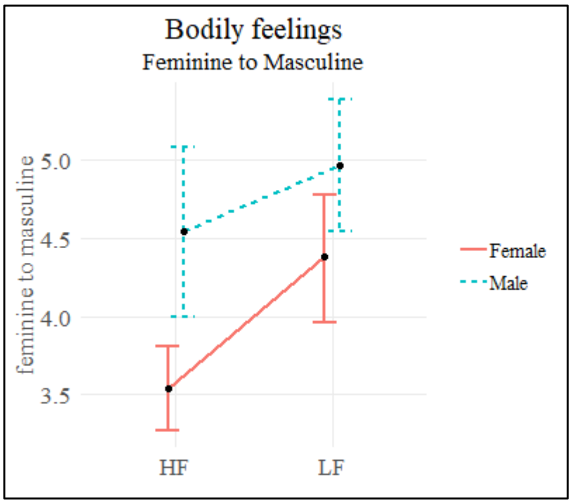


*Figure D.2: Answers to the feminine-masculine bodily feelings questions for male and female participants. A higher score equals a more feminine self-perception. Black dots represent the mean scores and error bars represent confidence intervals.*

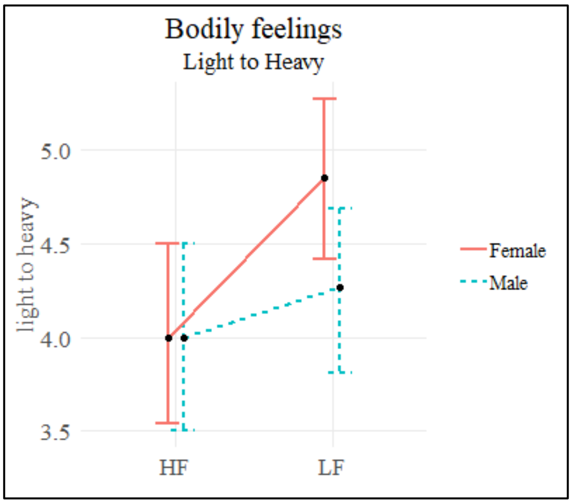


*Figure D.3: Answers to the light-heavy bodily feelings questions for male and female participants. A higher score equals a more feminine self-perception. Black dots represent the mean scores and error bars represent confidence intervals.*

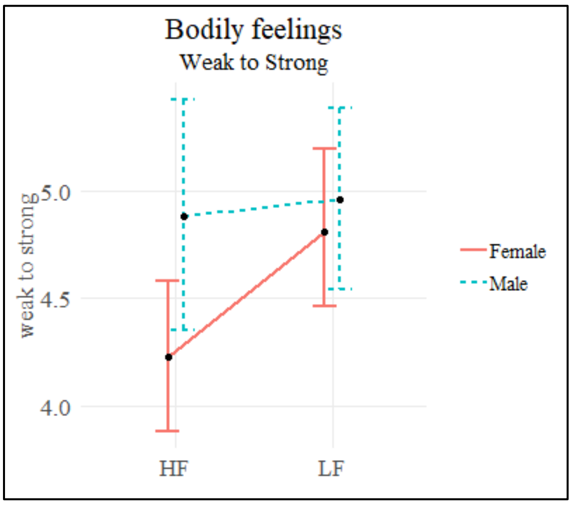


*Figure D.4: Answers to the feminine-masculine bodily feelings questions for male and female participants. A higher score equals a more feminine self-perception. Black dots represent the mean scores and error bars represent confidence intervals.*

**E – Additional Material (Information sheets for Experiment I and II and Consent form)**

## Information Sheet for Participants in Research Studies

*You will be given a copy of this information sheet.*

Title of Project: **Sonification for gym activity: Bodily feelings and Cognition**

This study has been approved by the UCL Research Ethics Committee as Project ID Number: **UCLIC/1516/003/StaffBerthouze/Newbold**

Name, Address and Contact Details of Investigators:

Dr Nadia Bianchi-Berthouze
UCL Interaction Centre
66 - 72 Gower Street,
London WC1E 6EA
United Kingdom
020 3108 7067

We would like to invite you to participate in this research project carried out in collaboration with Dr Ana Tajadura-Jiménez based at the Computer Science Department, Universidad Carlos III de Madrid, Spain and Dr Christian P. Janssen based at the Social and Behavioural Science Department, Utrecht University, Netherlands. The study aims to explore how sensory stimulation during walking affects behavior and social cognition. This study is focused on cisgender individuals without (a history of) eating disorders. You should only participate if you want to; choosing not to take part will not disadvantage you in any way. Before you decide whether you want to take part, please read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information.

The research takes place in three parts. First, you will be asked to complete a digital word sorting task and a pictorial questionnaire.

Thereafter, you will be asked to perform a task two different times, each lasting about 10 minutes. For this task you will wear headphones, through which you will listen to environmental sounds and a pair of sandals. We may also ask you to wear movement sensors attached to your body with rubber bands. Then, you will be asked to march in place for 30 seconds and take a few steps on a wooden corridor. Please focus on this walking task. Immediately after you will be asked to complete the digital word sorting task and pictorial questionnaire again. Then, you will be asked to answer a few other questionnaires on your experience during the task. This procedure will be repeated a second time with different sounds.

Finally, you will be provided with a questionnaire for collecting data on your body perception and demographics.

The experiment does not involve any risk for you. The whole session lasts about 50 minutes. You will be fully debriefed. For taking part in the study, you can choose to have 1 academic credit, to participate in a raffle for one of three 30 £ vouchers or to recruit me for an experiment of your own (please discuss this option with me).

It is up to you to decide whether or not to take part. If you choose not to participate, you won't incur any penalties or lose any benefits to which you might have been entitled. However, if you do decide to take part, you will be given this information sheet to keep and asked to sign a consent form. Even after agreeing to take part, you can still withdraw at any time and without giving a reason.

All data will be collected and stored in accordance with the Data Protection Act 1998 and the General Data Protection Regulation (GDPR). Researchers working with me will analyze the data collected. Anonymous data will be shared with Dr Christian P. Janssen at Utrecht University in the Netherlands (see website https://www.uu.nl/staff/CPJanssen) and Dr Ana Tajadura-Jiménez and her team at Universidad Carlos III de Madrid, Spain (see website http://dei.inf.uc3m.es/dei_web/dei_web/?page=people).

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020 3108 7067

We would like to invite you to participate in this research project carried out in collaboration with Dr Ana Tajadura-Jiménez based at the Computer Science Department, Universidad Carlos III de Madrid, Spain and Dr Christian P. Janssen based at the Social and Behavioural Science Department, Utrecht University, Netherlands. The study aims to explore how sensory stimulation during walking affects behavior and social cognition. This study is focused on cisgender individuals without (a history of) eating disorders. You should only participate if you want to; choosing not to take part will not disadvantage you in any way. Before you decide whether you want to take part, please read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information.

The research takes place in three parts. First, you will be asked to complete a digital word sorting task and a pictorial questionnaire.

Thereafter, you will be asked to perform a task two different times, each lasting about 10 minutes. For this task you will wear headphones, through which you will listen to environmental sounds and a pair of sandals. We will also ask you to wear movement sensors attached to your body with rubber bands. Then, you will be asked to march in place for 30 seconds and take a few steps on a wooden corridor. Please focus on this walking task. Immediately after you will be asked to complete the digital word sorting task and pictorial questionnaire again. Then, you will be asked to answer a few other questionnaires on your experience during the task. This procedure will be repeated a second time with different sounds.

Finally, you will be provided with a questionnaire for collecting data on your body perception and demographics.

The experiment does not involve any risk for you. The whole session lasts about 50 minutes. You will be fully debriefed. For taking part in the study, you can choose to have 1 academic credit or to receive £7.

It is up to you to decide whether or not to take part. If you choose not to participate, you won't incur any penalties or lose any benefits to which you might have been entitled. However, if you do decide to take part, you will be given this information sheet to keep and asked to sign a consent form. Even after agreeing to take part, you can still withdraw at any time and without giving a reason.

All data will be collected and stored in accordance with the Data Protection Act 1998 and the General Data Protection Regulation (GDPR). Anonymous movement data will be stored on non-EU servers. You will not be identifiable from this data. Researchers working with me will analyse the data collected. Anonymous data will be shared with Dr Christian P. Janssen at Utrecht University in the Netherlands (see website https://www.uu.nl/staff/CPJanssen) and Dr Ana Tajadura-Jiménez and her team at Universidad Carlos III de Madrid, Spain (see website http://dei.inf.uc3m.es/dei_web/dei_web/?page=people).

## Informed Consent Form for Participants in Research Studies

***(This form is to be completed independently by the participant after reading the Information Sheet and/or having listened to an explanation about the research.)***

Title of Project: **Sonification for gym activity: Bodily feelings and Cognition**

This study has been approved by the UCL Research Ethics Committee as Project ID Number: **UCLIC/1516/003/StaffBerthouze/Newbold**

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**Participant's Statement**

I …………………………………………......................................

agree that I have

- read the information sheet and/or the project has been explained to me orally;
- had the opportunity to ask questions and discuss the study; and
- received satisfactory answers to all my questions or have been advised of an individual to contact for answers to pertinent questions about the research and my rights as a participant and whom to contact in the event of a research-related injury.
- I understand that I must not take part if I am not physically able to do the tasks
- Given this I am happy to engage in mild physical activity and wear non-intrusive biosensors

For the following please circle "Yes" or "No" and initial the point.

_____ I agree to be contacted in the future by UCL researchers who would like to invite me to participate in follow-up studies YES / NO

I understand that I am free to withdraw from the study without penalty if I so wish, and I consent to the processing of my personal information for the purposes of this study only and that it will not be used for any other purpose. I understand that such information will be treated as strictly confidential and handled in accordance with the provisions of the Data Protection Act 1998 and the GDPR.

Signed: Date:

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**Investigator's Statement**

I ……………………………………………………………………..

confirm that I have carefully explained the purpose of the study to the participant and outlined any reasonably foreseeable risks or benefits (where applicable).

Signed: Date: