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Department of Brain and Behavioral Sciences (DBBS)
MSc in Psychology, Neuroscience and Human Sciences

"When I End and You Begin": Exploring the relevance of Graphesthesia in Interoception Assessment Through Caloric Vestibular Stimulation

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It is said that the blood is thicker than water… However, the original idiom rightfully acknowledged how the blood of the covenant shall be thicker than water of the womb. I think of my life companions, whom I found to be an inexhaustible a source of inspiration, hope, and support, which would keep me afloat during these years. I am especially thankful for my friends as their trust and belief in me have had sustained my sanity in these uncertain times.

List of abbreviations

BID - Body Image Disorders

CVS – Caloric Vestibular stimulation

FO – Focus Object

1PP – First Person Perspective

3PP - Third Person Perspective

GA – Gestational Age

RHI – Rubber Hand Illusion

SCCs – Semicircular Canals

SP – Somatoparaphrenia

SPP – Second Person Perspective

VOR – Vestibulo-Ocular Reflex

Chapter 1: Introduction

"Am I the one who is sitting on the stone, or am I the stone on which he is sitting?"

Carl Jung, 1962

Borrowing from Jung's, I am starting my thesis with a question - where the sense of self ends to meet the external world. While this is a question that evokes a certain degree of introspection, the real challenge of studying body-ownership is best to be approached via the study of the bodily signals from which the sense of self is assembled. How the brain assembles a coherent sense of self from the signals arising within the body remains one of the central questions of cognitive neuroscience. This thesis approaches that question through the vestibular system, arguing that its contribution to bodily self-awareness places it closer to interoception than its classical role in balance would suggest. Growing number of works on Interoception suggests that Vestibular System (VS) has broader functional significance than previously assumed, contributing not only to spatial orientation but also to the multisensory representation of the body from which the sense of self is constructed. In an attempt to contribute to the existing research, this thesis will approach interoceptive processing with a novel tool, graphesthesia, paired with caloric vestibular stimulation to test whether altering the vestibular signal measurably shifts the perspective from which bodily sensations are interpreted.

1.1. Interoception

According to the James-Lange theory, emotional experience results from bodily changes and does not precede these. However, Craig (2002, 2009) proposes that the insular processing that gives rise to awareness of the body's physiological state also gives rise to subjective feeling, where emotions are in essence feelings of the body. According to this perspective, interoception is not one of sensory modalities (touch, vision, hearing, taste, and smell) but the substrate from

which affective experience and a sentient self are constructed. Studies have shown how internal body signals are linked to bodily self-consciousness (for example, neural responses to heartbeats covary with self-location and first-person perspective, Park et al., 2016). Interoception provides one part of the answer to how a coherent inner map of the self is constructed from bodily signals, the same explanatory project to which this thesis argues the vestibular sense also contributes Interoception is the perception of internal stimuli and sensations. It is the sense through which we receive signals originating from within the body to biological regulation. This term was first introduced by Sherrington (1906), when he divided the sensory surfaces of the body into three classes - exteroceptive, interoceptive, and proprioceptive. Exteroceptors to act on stimulation from the outside world, proprioceptors which signal the position and movement of the body itself; and interoceptors which he limited specifically to receptors of the viscera. Throughout the 1900s, the general conception of a sense of the body's internal state underwent several terms. These were coenaesthesis, coenesthesia, somesthesis. It later settled on interoception in its now-dominant, expanded form (Ceunen, Vlaeyen, & Van Diest, 2016). The sense of interoception is said to underlie our feelings of hunger, thirst, temperature, breathlessness, cardiac activity, gastric distension, nociception (pain), fatigue and more. Craig's (2002) redefinition of interoception as the experience of the physiological condition of the whole body, along with the temperature, itch, muscular and visceral pain, sensual touch and all other signals conveying information about the homeostatic condition of the body, has made for a decisive modern re-framing.

However, Ceunen et al. Raise the question wether interoception can be limited by this definition. Specifically, they point to the narrowing down of the definition to sensory signals originating from the internal organs only, when it actually might refer to all sensations that are

physiologically relevant. If interoception is defined by a specific type of receptor or nerve, then the vestibular sense cannot be part of it because it has a nerve and end organs by definition. According to the more inclusive view, if interoception is a central integrative representation of the state of the body, then the relevant question is not which nerve carries a signal but rather whether that signal is relevant to the brain's model of the bodily self. Present research supports the "Interoception," as the collection of activities by which the nervous system senses, integrates, interprets, and regulates signals from inside the body (Chen et al., 2021; Khalsa et al., 2018). The limits between these categories are increasingly considered as being permeable, and one of the arguments of this thesis is that the vestibular apparatus plays a significant role in the interoceptive awareness in humans.

Contemporary science's understanding of interoception is based on a thorough account of the afferent pathways and their cortical representations that pass on signals and process them from the body in relation to its internal state, devised most influentially by Craig (2002, 2009). This model asserts that small-diameter afferent fibres innervating body tissues convey afferent information relating to physiological condition, and that the posterior insula serves as the interoceptive cortex, which receives a body-state's topographically organised, modality-specific map (like the primary somatosensory cortex). According to Craig's model, the initial interoceptive representation in the posterior insula becomes clearer along a posterior to anterior gradient through the mid-insula to anterior insula. Here, it integrates with signals of emotional, motivational, cognitive and social significance. At the point at which a physiological state becomes a feeling, there is a point of awareness in the brains neural correlate. Thus, according to Craig, interoception and allostasis may be considered crucial for homeostasis.

The posterior and mid-insula, which are significant for the interoceptive processing, are also a principal site of vestibular cortical processing, and a convergence zone for vestibular, somatosensory and visceral signals. This interconnectedness makes a strong case for treating the vestibular contribution to self-perception as continuous with, rather than separate from, interoception. Evidence of a relationship between interoceptive awareness and insular function has been investigated over the past 20 years, first coming from Critchley et al. (2004), who observed an effect during a heartbeat-detection task where activity in the right anterior insular/opercular cortex predicted individuals' accuracy at that same task. They also found that local grey-matter volume in this region predicted interoceptive accuracy and subjective estimates of visceral awareness. Since then, numerous works attempted to research if and how the insula integrates interoceptive and exteroceptive and emotional information in its subregions (Simmons et al., 2013; Gu, Hof, Friston, & Fan, 2013), and interoception is now placed within the context of a system of visceral influences on brain and behaviour (Critchley & Harrison, 2013). Interoception is a construct and not a single measurable quantity. As a result, its scientific study has required the development of ways to operationalise interoception. Furthermore, the acknowledgment that different operationalisations measure genuinely different things has been one of the most consequential methodological developments in the field. According to Garfinkel, Seth, Barrett, Suzuki and Critchley (2015), the dominant framework is that interoception is not unitary, but consists of at least three dissociable dimensions: accuracy, sensibility, and awareness. Interoceptive accuracy refers to the objective performance on a task that measures interoception – cardiac is the most common. In the heartbeat-counting task (Schandry, 1981), where participants count their heartbeats in varied length intervals without tracking their pulse with the score being a measure of accuracy against the true count registered by the researcher. In

heartbeat-discrimination tasks, participants judge whether external stimuli were synchronous with, or asynchronous to, their own heartbeat. 2nd dimension is interoceptive sensibility: The self-evaluated, dispositional tendency to be interoceptively focused, assessed through interviews and questionnaires (e.g., Multidimensional Assessment of Interoceptive Awareness) rather than through performance on tasks. The third is interoceptive awareness (in Garfinkel et al.'s specific sense): metacognitive insight into one's own interoceptive accuracy – the correspondence between how well one actually performs and how confident one is, operationalised for example as the trial-by-trial relationship between confidence and accuracy. A person's objective accuracy is only partially predicted by their self-reported sensibility or by their metacognitive awareness. Also, the dimensions tend to be aligned only in persons with high interoceptive accuracy. Thus, studies need to specify which dimension they measure. Seemingly inconsistent findings in the literature usually reflect a conflation of different dimensions. For methodological transparency, it must be recognized that the heartbeat counting task has been subjected to sustained critique on the grounds that performance can be confounded by knowledge of resting heart rate, beliefs about heart rate, and time-estimation strategies, meaning it may not be a pure index of cardiac perception. The field has thus shifted towards complementary methods and more judicious task design, including the present study which employs the method of Graphesthesia, which will be discussed in detail further.

In the last few years, the most influential development in the theory of interoception involves its reformulation within the predictive-processing framework, where the brain is not a passive receiver of sensory input like a radio transmitter. Based on (usually) limited data it tries to predict in real-time the most likely cause of the sensory signal received, and updates the model of reality in its internal representation. According to this viewpoint, perception constitutes a type

of controlled hallucination, which serves as evidence to constrain sensor action. Seth (2013; Seth et al, 2012) extrapolated this logic from exteroception to the interior of the body, giving rise to the notion of interoceptive inference. The experience of bodily and emotional states does not passively arise from ascending visceral signals and instead reflects top-down predictions by the brain about the causes of these signals, corrected by interoceptive prediction errors. According to Seth, emotions refer to the contents of active inference on the causes of interoceptive afferents. This is a contemporary and inferential reworking of appraisal and James-Lange theories. Using the same framework, it is also possible to account for the sense of bodily presence and selfhood, and importantly, a route into understanding psychiatric disorders of selfhood as disorders of interoceptive inference, where aberrant predictions or aberrant weighting of prediction error distort experience of body and self.

According to Barrett and Simmons' (2015) complementary anatomically explicit model, EPIC model, predictions about what is happening internally originate in agranular visceromotor regions (i.e., the anterior insula and anterior cingulate). These predictions descend in top-down fashion to regulate the body. Concurrently, ascending visceral signals convey prediction errors that adjust those predictions. This is important for establishing the nature of interoceptive experience. Interoceptive experience mainly reflects limbic predictions constrained by ascending input. It is not the case that those predictions originate in the body and travel inward. An important aspect of this and related accounts concerns precision – the brain's estimation of the reliability of a signal, which determines the degree to which a given prediction error updates the model. Aberrant precision may be a candidate mechanism for a range of interoceptive and affective disorders (Seth & Friston, 2016; Barrett, Quigley, & Hamilton, 2016; Allen, 2020).

One important extension is linking interoceptive inference with active inference and allostasis. The predictive interoceptive system does not merely reflect the bodily state but instead relies on predictions to act, both autonomically and behaviourally, to fulfill those needs before they arise, resulting in minimization of expected prediction error over time. According to this perspective, interoceptive predictions are recorded in set-points that initiate autonomic homeostatic regulation and have been reframed as allostatic and interoceptive inference disorders (Barrett, Quigley & Hamilton, 2016). To be brief, interoception is altered from a passive sense that receives information to a process where active deceptive modeling is used to regulate the body.

The predictive-processing account is vital to the current thesis. To begin with, it provides the theoretical language in which the main ideas of the thesis are framed: that disturbances of bodily self i.e. depersonalisation, distorted body representation, altered perspective, reflect unresolved prediction error or aberrant precision in the brain's model of the body applies equally to interoceptive and to vestibular signals and unifies the clinical phenomena reviewed in previous chapters under one principle. The framework also erases the hard boundary between sensory channels. If interoception is defined not by a receptor class but by its contribution to the brain's predictive model of the body state, then any afferent stream that feeds that model including the vestibular participates in interoceptive inference. The extended view of interoception developed in the thesis relies on this conceptual move.

A study conducted by Nakul, Dabard, Toupet, Hautefort, van Nechel, Lenggenhager and Lopez (2020) considers that there are tight functional and anatomical links between vestibular and interoceptive systems, where the vestibular sense contributes to interoceptive processing, and disrupting it alters interoception. Using a heartbeat-tracking task, they assessed cardiac interoceptive accuracy (CIA) in bilateral vestibulopathy (BVP) taking heartbeats into account.

Moreover, it was measured on a confidence scale, general body awareness, as well as measures of self-location and self-body closeness. They did in comparison to twenty-five healthy controls. The outcome of the study shows little difference. It shows patients and controls do not vary in cardiac interoceptive accuracy, confidence, or body awareness It also states that long-term bilateral vestibular loss does not, in itself, reduce cardiac interoception or bodily self aspects. The researchers assumed that the phenomenon is likely true at least for some people but maybe not for everybody. They measured interoceptive accuracy using a three-alternative forced choice task in which participants watched a series of three dots on screen. Initially, self-anchoring and perspective-taking was examined, and it was found that compensated chronic bilateral vestibular loss (deroualle et al., 2017) is no longer disturbing the bodily-self measure. In agreement with a vestibular-autonomic link, also it has been demonstrated that cardiorespiratory variables, such as heart rate, blood pressure (Jáuregui-Renaud et al., 2000), and neuronal patterns are tuned to vestibulo-autonomic disruption (Balaban & Porter, 1998) and modulated by caloric vestibular stimulation. The current evidence compiled suggests that the vestibular and interoceptive systems are anatomically and functionally coupled. One might conclude that both systems are significant in emotional processing and upholding the sense of bodily self.

1.2. Proprioception

According to Chen and colleagues (2021), the neural activity of muscles and connective tissues involved in proprioception can be connected to interoception. It is noted that the anatomical boundaries between interoception and some forms of exteroception become fuzzy exactly in the case of proprioception and somatosensation. The functional criterion they propose allows for an alternative way to classify senses. Rather than by where their receptors lie, we can ask whether their signals represent the internal or external world. It is that, while housed in the same organ as

the exteroceptive auditory sense, the vestibular sense does not represent a state in the world that is external to the organism but rather the internal state of the animal's balance and orientation. Thus, on this functional criterion, the vestibular system belongs with interoception rather than exteroception. Research on interoception acknowledges that proprioception's inclusion or exclusion is an unresolved border question (Ceunen et al., 2016), and clinical accounts of the bodily self increasingly treat proprioceptive and interoceptive signals together as the joint 'raw data' for the body-self. A common computational view is that proprioception is essential for state estimation: to move accurately, the nervous system needs a good estimate of the current position and state of the body and limbs, so it can choose and update motor commands during goal-directed actions (Tuthill & Azim, 2018). In this view, proprioceptive feedback helps both choose an appropriate control plan before movement starts and fine-tune motor output while the movement is happening (Tuthill & Azim, 2018). Proprioceptive signals are combined with other sensory information, i.e. vision, to form a single estimate of limb position. When proprioceptive input is disrupted, i.e. tendon vibration, people make systematic errors in planning and executing movements, showing how important proprioception is for motor control (Tuthill & Azim, 2018). Returning to Sherrington's three-part conception of the senses, proprioception was considered to process the body's mechanical relation to space rather than its physiological state. Whereas Proske and Gandevia (2012) brought together under proprioception a set of senses generated by our own actions likelimb position and movement (kinaesthesia), force, effort and heaviness. Proprioception can be considered the perception of position and movement of the body, body parts relative to other body parts, and the ability to know with little visual input just where we have situated ourselves in space. Thus, it leads a person when they have to touch a finger to the nose with their eyes shut, to put one foot in front of the other in darkness and to keep the body in

posture all the time with no conscious attention. Logically, the sense of proprioception is catered for by receptors in our muscles, joints, tendons, and skin. It has been recognized that limb position and movement information is not generated by single receptors but by populations of afferents whose signals are combined centrally (Proske & Gandevia, 2012). The primary proprioceptors for position and movement are generally considered to be the muscle spindles. These specialised encapsulated receptors lie in parallel with the extrafusal muscle fibres (i.e. those fibres responsible for muscle contraction). Each spindle is innervated by a primary receptor afferent and a secondary receptor afferent. They signal muscle length (and its rate of change). Because muscle length changes with joint angle, spindle discharge tells the nervous system the position and movement of the limb. Golgi tendon organs are located in the muscle–tendon junction that lies in series with muscle fibres. It signals the tension in the muscles and with spindles, contributes to the sensory perception of force and heaviness. Full proprioceptive acuity requires contributions from muscles, joints and cutaneous afferents (Proske & Gandevia, 2012). Cutaneous (skin) receptors, especially those sensitive to skin stretch, give a third afferent input which is especially important at the digits. Information from a significant amount of muscle afferents is sent to the cerebellum (via the spinocerebellar tracts), where it is involved in the largely unconscious control of movement and posture. Most relevant evidence for the central constructive nature of proprioception comes from experimental phantom limbs. According to Proske and Gandevia (2012), sensory inputs that arise during movement are compared to a reference map in the central nervous system; this map is used to identify the position of body parts, showing that position is a construction rather than a direct observation. When peripheral nerves are blocked, the motor areas of the brain can give rise to conscious sensations of displacement or movement of the limbs in the complete absence of any afferent input. This

evidence suggests that centrally generated signals likely motor commands or their corollary discharges contribute to the proprioceptive percept (Proske & Gandevia 2012). This interaction between afferent input and a model characterizes the operation of every sense. The model provides feedback that shapes the afferent input. We call virtues responses feedback-modulated interactions. It is very easy to see how this applies to proprioception, which is the sense of body position.

This constructive characteristic of proprioception is the reason it underlies body representation and the sense of self. According to Cole and Proske & Gandevia (2012) the sense of limb position is essential to a sense of self. Proprioception contributes to the body schema, an implicit continuously updated representation of spatial configuration used to guide action discussed in the body-representation chapter. The rubber-hand illusion a phenomenon in which conflicting visual information captures our perception of the position of a limb we can feel demonstrates how the brain weights proprioception and other sensory modalities in the experience of our own body, and how this weighting can be distorted. Disturbances of proprioceptive precision have correspondingly been implicated in disorders of the bodily self: aberrant proprioceptive prediction errors, for instance, have been linked to abnormally flexible self-boundaries in the schizophrenia spectrum, within the same predictive-processing framework this thesis employs. The vestibular sense and proprioception are functionally integrated as well as parallel in their classification systems. The Vestibular organs signal the motion and orientation of the head; to derive the motion and orientation of the body, the nervous system must combine vestibular signals with proprioceptive signals about the position of the head on the trunk, principally neck proprioception. The vestibular nuclei and cerebellum neurons are known to receive vestibular and neck-proprioceptive inputs integration of which is thought to be the basis of the

transformation from head-centred to body-centred reference frames which is needed for vestibulospinal postural reflexes and for the perception of body motion independently of head motion. Single-unit work in the cerebellar vermis, for example, has identified populations of neurons that dynamically represent an intermediate-state signal between head movement and body movement through the integration of vestibular and neck-proprioceptive signals (Cullen et al). Consequently, the information generated by proprioceptors and the vestibular sense can be seen as the spatial reference frame for the body, which the vestibular contributions to self-perception were identified as a measuring axis in the graphesthesia and body-representation chapters. This reinforces the notion that the vestibular and proprioceptive senses, which build the body-centred spatial frame, and senses that represent the body's internal physiological state are not processed separately but converge together in the vestibular nuclei, cerebellum, and the posterior and mid-insula (Chen et al., 2021: and see the vestibular-system chapter for the convergence).

1.3. Vestibular system

The vestibular system is among the first senses to begin embryonic development, with the primordium of the inner ear beginning to form around the gestational age (GA) of 4 weeks and the semicircular canals developing their structure from GA 6-10 weeks (Lim & Brichta, 2016; Chacko et al., 2019). Around the 9th week hair cells begin to emerge in the utricle, establishing synaptic connections with the vestibular nerve fibers by GA 13 week; between GA 8-10 weeks the semicircular canals further develop into lateral, anterior, posterior structures; throughout GA 29-36 weeks the vestibular nerve is successfully myelinated (Chacko et al., 2019). Notably, both maternal bodily motion and fetal self-initiated general movements provide spatial information crucial for the structural maturation of the central vestibular pathways (Lim & Brichta, 2016;

Fagard et al., 2018; Einspieler et al., 2021) further influencing fetal brain development and motor behavior. After natural conclusion of the embryonic period, a now infant's vestibular apparatus is considered to be operational enough for the early sensorimotor organization and the modulation of some primitive reflexes such as vestibulo-ocular reflex (VOR), vestibulo-spinal reflex and Moro reflex (Einspieler et al., 2021). As we take our very first breath, the body becomes increasingly aware of the fact that we have left the comfort of mother's womb and that some adjustments are due to be made. This sudden change, from having access to all the necessary nutrients and perceiving the outside world only through second-hand information, marks the beginning of a life-long commitment to the demanding state of simply being alive. We start to get more accustomed to our body existing in this new environment by testing its limits through awkward, uncoordinated motions - each bringing one closer to the concept of self.
The VOR helps people to keep their eyes on an object that they are trying to view even when they are moving their head. This reflex sends compensatory eye movements via the vestibular nuclei through the medial longitudinal fasciculus to the oculomotor nuclei in an equal and opposite direction to the head movement. It is VOR that creates the slow phase of vestibular nystagmus that you will read about in the nystagmus chapter. Vestibulospinal reflexes are mediated bilaterally via the medial and lateral vestibulospinal tracts, which modify axial and limb muscle tone to sustain postural stability. The vestibulo-collic reflex enables the head to remain stable on the trunk. The thalamus, especially the nuclei in the ventral posterior and ventral lateral categories, also get ascending projections that relay vestibular information forward to the cortex, thus establishing the thalamocortical vestibular system (Lopez & Blanke, 2011). Brainstem vestibular nuclei are connected to brainstem autonomic centres which mediate

vestibulo-autonomic and vestibulo-sympathetic reflexes with which head position and/or movement get coupled to cardiovascular and other autonomic regulation.

The structure operates based on inertia: when the head rotates in a particular direction and its angular speed changes, the endolymph in the canal lags those changes due to inertia. As a result, there will be relative fluid movement within the semicircular canal that pushes against the cupula. The cupula is a gelatinous structure that bends the cilia of hair cells located within it. As these cilia bend, the firing of vestibular afferents is altered (Lim & Brichta, 2016). Since the canals reflect the relative movement of the endolymph, they actually act to the transducer of angular acceleration but, over the range of natural head movements, they signal angular velocity to the brain. The bony labyrinth of the inner ear, found in the petrous part of the temporal bone, contains the vestibular end organs and is connected to the cochlea. The membranous labyrinth lies within the bony labyrinth. The membranous labyrinth consists of interconnected sacs and ducts filled with endolymph, which is rich in potassium (K+) and low in sodium (Na+). Spaces between the membranous and bony labyrinths are filled with perilymph, which is like ordinary extracellular fluid (high Na+, low K+). Sensory transduction relies on this ionic arrangement as discussed next. The vestibular labyrinth contains five other end organs on each side of the head, three semicircular canals which are sensitive to angular (rotational) acceleration and two otolith organs the utricle and the saccule which are sensitive to linear acceleration (Lim & Brichta, 2016; Cleveland Clinic, 2026). The anterior (superior), posterior (inferior), and lateral (horizontal) semicircular canals are arranged to sample head rotation in three planes of space. Each canal on one side is functionally paired with a canal on the opposite side. The two canals that are paired are coplanar and operate in a push–pull fashion. Each canal is a ring filled with fluid, which at one end widens into a swelling called the ampulla. The sensory epithelium, or the

crista ampullaris, has hair cells that project their cilia into a gelatinous mass, the cupula. This partition spans the ampulla and makes a fluid-tight partition. A thermal gradient along the (horizontally oriented) lateral canal establishes a convective flow of endolymph, causing a deflection of the cupula without any actual movement of the head. The macula, a sensory epithelium, is found in both the utricle and saccule. Like the canals, the hair cells in the otolith organs (utricle and saccule) project their cilia into a gelatinous layer. However, in otolith organs this layer is capped by a dense otolithic membrane studded with crystals of calcium carbonate called otoconia (or otoliths – literally "ear stones"). Since the otoconia make this membrane much denser than the surrounding endolymph, it responds to linear forces: when the head is tilted, gravity displaces the weighted membrane relative to the sensory epithelium; when the head undergoes a linear (translational) acceleration, inertia does the same. The shear causes the hair-cell cilia to bend and modulates afferent firing ((Lim & Brichta, 2016). The utricular macula is roughly horizontal while the saccular macula is approximately vertical. Thus, the two maculae orientate in complementary planes and so between them they detect linear accelerations or head tilts in all directions. The otolith organs (saccule and utricle) trigger responses to both the static and dynamic acceleration of the head relative to the pull of gravity, with the dynamic orientation also incorporating an eye response reflex component. All five end organs use the hair cell as their common currency, the mechanoreceptor that transduces the mechanical deflection of cilia into an electrical signal. The stereocilia distribution of a hair cell, the native structure its transduction machinery operates, bears a striking resemblance to the stereocilia distribution of a kinocilium, which hair cells can operate on an entirely different cell type. Simultaneously, the kinocilium serves as a reference point for the stereocilia of neighboring hair cells, effortlessly allowing the hair bundle to maintain its directionality even in the event of a small misalignment

of the entire kinocilium structure. The cilia are surrounded by potassium-rich endolymph that generates a transduction current when the channels open. This bidirectional modulation around a resting discharge rate, dependent on polarity, allows a single epithelium to signal the direction and magnitude of head motion.

Unlike vision, audition, and somatosensation there is no single, agreed upon primary cortical area for the vestibular signal. Instead, the vestibular signal is processed in a widely distributed network of multisensory areas in which vestibular input is integrated with inputs from other modalities rather than represented in isolation (Lopez & Blanke, 2011; Eulenburg et al., 2011). Vestibular signals are not released to a single primary cortex but are distributed across several regions of the brain. These include the parieto-insular vestibular cortex, the temporo-parietal junction, and the insula. These regions also process somatosensory and visual signals and important for the interoceptive argument, visceral signals. According to Blanke (2012), the integration of multisensory bodily signals in the brain occurs in temporo-parietal and premotor regions. Furthermore, the temporo-parietal junction is believed to be involved in self-location and first-person perspective. Research indicates that the vestibular contribution to bodily awareness is largely located to a right-hemispheric network. Through this shared substrate provided by the posterior and mid-insula convergence zones, the vestibular and interoceptive inputs may interact to create a coherent representation of bodily self. The vestibular cortex's region is most commonly labelled as the parieto-insular vestibular cortex (PIVC). The PIVC was first characterised in non-human primates (specifically macaque monkeys) by Guldin and Grüsser (1998). Approximately one-third of the PIVC's neurons respond to vestibular stimulation, which is completely normal. Many other PIVC neurons respond to visual input and somatosensory input (Guldin & Grüsser, 1998). The PIVC located in primates is the parietal

operculum, retroinsular cortex, and posterior insula area. In humans, the homologous region has been localized with some dispute. Functional imaging implicating the temporo-parietal junction, as well as the superior temporal gyrus, posterior insula, inferior parietal lobule. Eickhoff, Weiss, Amunts, Fink, and Zilles (2006) and Eulenburg et al., 2011) carried out two meta-analyses on the vestibular neuroimaging that converged on the parietal operculum area OP2, extending to the retroinsular/posterior insular cortex, as the best candidate for the human core vestibular cortex and homologous PIVC in primates. In addition to this core area, the human vestibular network encompasses the anterior insula, somatosensory cortices (including area 3aV and second somatosensory area, SII), intraparietal sulcus, vestibular region of the cingulate, and premotor areas; it is thus a genuinely distributed system (Lopez & Blanke, 2011). Other research has since proposed that a nearby visually-responsive area in the parieto-insular cortex (PIC) should be distinguished from vestibular and motion-sensitive areas in PIVC proper. The posterior-insular area that is identified in the interoception chapter, following Craig (2002, 2009), is simultaneously seen as participating in interoceptive awareness and the monitoring of body states and as the main vestibular sensory cortex, where electrical stimulation in the has been known to elicit sensations of bodily movement (Eickhoff et al., 2006; Eulenburg et al., 2011). This offers a reasonable basis to form the link between vestibular illness and depersonalisation, the relationship between the vestibular system and body representation and ownership, the interaction between felt ownership and thermoregulatory physiology during caloric stimulation, and the hypothesised sensitivity of graphesthesia to vestibular manipulation. If the areas of the brain responsible for processing vestibular and interoceptive signals overlap and the same neuronal populations are responsible for integrating them, then the vestibular sense is

anatomically poised to impact the body state that is essential for interoception in its inclusive sense.

The vestibular information afferent fibres are distinguished by their continuing high resting (tonic) discharge in the absence of head movement, so that head movement is encoded as an increase or decrease on this background – the configuration that makes possible the push-pull comparison between the two labyrinths. Conventional classification of vestibular afferents into regular and irregular classes is based on the regularity of their resting discharge. Irregular afferents are shown to be more sensitive to the high-frequency and galvanic components of stimulation. This classification is gradual in the single unit work presented in the stimulation chapter (Goldberg, Smith, & Fernández, 1984), and will be relevant for how galvanic vestibular stimulation recruits the afferent population. Most of the primary afferents end in the vestibular nuclear complex, which consists of four nuclei (superior, lateral, medial, and inferior) situated in the floor of the fourth ventricle, in the brainstem. A smaller number project to the cerebellum, which is particularly aimed at the flocculonodular lobe, calibrating and adapting vestibular reflexes. At the same time, neurons in the medial and descending vestibular nuclei display a different behavior during REM sleep, exhibiting bursts of rapid firing that are locked to the rapid eye movements themselves (Bizzi et al. 1964). This links the vestibular nuclei directly into the phasic events of REM sleep in agreement with their established role in oculomotor control via vestibulo-ocular pathways. The nuclei during wakefulness generate the slow phase of the vestibulo-ocular reflex; during REM sleep the same circuitry participates in the generation of the characteristic saccades in the absence of any real head motion. These nuclei active and functional across the sleep-wake cycle. Their function is repurposed rather than switched off. The vestibular nuclei thus remain active node of the brainstem oculomotor network. Apart from

influencing oculomotor functions, vestibular nuclei exert control over autonomic function during REM sleep, showing for the first time that vestibular influences during sleep affect cardiovascular and other autonomic variables (Morrison & Pompeiano, 1970).

1.4. Bilateral vestibular function and body representation

According to Ferrè, Bottini, and Haggard (2012) limiting VS to only postural and gaze control severely underestimates the reach of vestibular signals which in fact participate in the construction of bodily self-awareness at multiple levels. The vestibular organs represent the only sensory estimate of the motion of the head and its orientation relative to gravity. These vestibular reference signals allow an estimate of the displacements to be extracted over time. For this reason, they provide a reference frame against which signals from the body's parts and posture must be interpreted. Disturbing or removing that reference would thus be expected to have consequences for how the body is represented, and It can be helpful to adopt the multi-level taxonomy of body processing. They distinguish three processes, following the influential models of somatic cognition. Firstly, somatosensation is the initial sensory processing of stimuli on the body, like touch. Secondly, somatoperception: the forming of perception (from the raw sensory input) of the body as an object with size, shape and posture. A more abstract knowledge of our body as an object in the world is the third component. According to a review by Ferrè and Haggard, vestibular signals affect different levels of abstraction and processing. More specifically, they modulate tactile processing, affect perceived body dimensions and posture, and even influence conceptual knowledge of the body. This means that our sense of balance affects how we see our body itself. The vestibular system contributes to body representation not just in its classical sensorimotor capacities, but also as part of a broader multisensory network through

which the brain constructs and maintains a coherent model of the body in space. In their paper, Ferrè and Haggard (2016) propose a three-level framework where vestibular contributions to body representation differ in somatosensation, somatoperception, and somatorepresentation. Vestibular signals are higher-order contributors to body-self knowledge This is supported by neuroimaging evidence (Bottini et al., 2005): vestibular and somatosensory projections overlap in the secondary somatosensory cortex, putamen, insula, premotor cortex and inferior parietal cortex. CVS activates brain regions that also respond to tactile stimulation of the contralateral hand. The most direct experimental route to establishing a vestibular contribution to body representation is to stimulate the vestibular system artificially in neurologically healthy people and observe the consequences. Two strategies are usually found in scientific literature: caloric vestibular stimulation (CVS), in which the ear canal is irrigated with water above or below body temperature, and galvanic vestibular stimulation (GVS), in which a weak current applied over the mastoid processes modulates the firing of vestibular afferents. The vestibular signal can be modified temporarily and reversibly with either. Vestibular stimulation has been shown to have a modulatory effect on tactile processing at the level of somatosensation. Lopez et al. (2012) observed that vestibular stimulation changes one's body schema, which is considered as the unconscious representation of spatial configuration of the body used to guide action – suggesting that a purely vestibular perturbation is able to modify perceptual configuration of the body. Prior research indicates that caloric stimulation alters aspects of bodily experience in healthy participants (Schönherr & May, 2016). This is supported by the finding that both dizzy patients and healthy participants undergoing caloric stimulation display distorted representations of their own body (Lopez et al., 2018).

1.5. Vestibular dysfunction

Vestibular dysfunction provides an in vivo model to study how the disruption of a bodily sense propagates disturbances in self- and world-experience, such as depersonalisation and derealisation. By itself, cross-sectional association cannot prove that vestibular dysfunction causes dissociative symptoms, as they may simply be associated, for example through shared comorbidity with anxiety. The most direct evidence for a causal contribution therefore comes from studies that manipulate vestibular input in otherwise healthy people and measure the emergence of dissociative experience. According to Lopez et al. (2018), the caloric vestibular stimulation (CVS) of both a dizzy patient and healthy participants distorted the perception of their own body. Recent research has focused on identifying specific components of the vestibular system that contribute to dissociative experiences and how the dysfunction of these components triggers such experiences. The model therefore identifies spatial disorientation and anxiety as mediators rather than simple co-relates, consistent with about 83% of studies in Cento et al. (2026) review identifying the two as the same. The findings of Kolev et al. (2014) independently confirm the modulator role of anxiety by showing its alteration of the expression of depersonalisation and derealisation symptoms in vestibular patients. While this information does not reduce the dissociative symptoms to “just anxiety”, it does suggest that the affective state of the patient shapes the strength of the experienced unreality of the underlying sensory disturbance. Lopez (2013) proposed a neuroscientific account of vestibular disorder induced body-self disownership, on the basis of the convergence of vestibular signals on visual and somatosensory signals in the temporo-parietal and insular cortex. The most notable clinical symptom is the out-of-body experience (OBE), where an individual experiences their centre of awareness as outside the body. Modern models claim that OBEs are due to a failure to integrate

visual, somatosensory, and vestibular signals with visual-vestibular dissonance somewhat central. Consequently, the dissociative symptoms of vestibular disease could be interpreted as a resulting malfunction from lost coherence in the spatial model of the body-self. Likewisel, disturbances arise when lost coherence of the interoceptive model occurs. The merging of vestibular, somatosensory and visceral signals in the posterior and mid-insula discussed above may provide a plausible anatomical substrate to define both these manifestations as a single problem of bodily self-modelling. The vestibular contribution to depersonalisation is thus one of the clearest clinical demonstrations that the sense of being a real, embodied self is assembled from bodily afferents. Importantly, the interoception in this extended sense that we have argued for here cannot be separated from sensing of the body in space.

Another such condition of disrupted self-perception and body-ownership would be somatoparaphrenia - a delusion typically occuring after a stroke, when a patient denies ownership of their own limb, sometimes attributing it to another person. It typically arises following right hemisphere damage, and is followed by a failure to move the affected limb, and a genuine belief that the limb does not belong to oneself. What makes somatoparaphrenia particularly relevant to the study of vestibular contributions to body representation is that its symptoms can be transiently reversed by CVS. Bisiach et al. (1991) were among the first to document this, reporting a patient who misidentified her left arm as belonging to her mother, and whose sense of ownership was temporarily restored following caloric vestibular stimulation. More recently, Salvato et al. (2018) approached the same phenomenon from a physiological angle, showing that the temporary remission of somatoparaphrenia following left-cold CVS in a chronic patient was accompanied by measurable increases in body temperature in both hands, with the magnitude of temperature change correlating with the degree of restored ownership.

1.6. Caloric Vestibular Stimulation

The vestibular stimulation discussed previously has been repeatedly mentioned as experimental means to research the bodily self-ownership in a healthy subject and as an instrument to temporary return body representation in the brain-damaged patient. This chapter discusses caloric vestibular stimulation (CVS) and galvanic vestibular stimulation (GVS), the two techniques which the bulk of that evidence rests. Both methods are non-invasive and can impact the vestibular signal in awake, behaving humans. In fact, it is this very ability - to directly manipulate a bodily afferent stream causally, as opposed merely to observing the effects of its stimulation on other processes - that makes both so useful for testing claims about the vestibular contribution to body representation, self-awareness, and, as this thesis will argue, interoception. The vestibular system is the balance-brain receptor in our inner ears. It senses our motion through space, as well as where gravitational up is with respect to our head. Let's take a graphical look at the vestibular system. A user can access this key natural sensor. It's our vestibular system. Just think of it as a pretty extension of our brain that sensors motion and orientation.

At the beginning, it is necessary to note the scope. CVS and GVS stimulate the vestibular system at different sites and with different characteristics. As a consequence, some of the controversies in the literature relate to whether CVS effects on spatial cognition have a genuine vestibular origin or are merely low-level oculomotor and attentional by-products, and these are further rooted in these mechanistic differences. Hence, the following account level mechanism is not preliminary background but rather is foundational to the rest of the argument dependent on it. Caloric vestibular stimulation is the older of the two techniques, introduced by Robert Bárány in the first decade of the twentieth century and recognised in the 1914 Nobel Prize in Physiology or

Medicine (Bárány, 1906). The external auditory canal of one ear is irrigated with water (or, in some protocols, air) at a temperature above or below body temperature so that, while lying supine in a position with the head raised approximately 30°, the horizontal semicircular canal is brought into a near-vertical plane. This positioning is essential to the classical mechanism: with the canal oriented in the vertical plane, the temperature gradient across it leads to the formation of convection currents in the endolymph fluid contained in the canal, and it is these currents which lead to a deflection of the cupula (Lopez and Blanke (2014).

Temperature determines whether the effect will be positive or negative. The discharge rate of afferents that innervate horizontal canal is increased by warm irrigation - this was an excitatory and ampullopetal effect. Cold irrigation was found to decrease the discharge rate which was an inhibitory effect. The vestibulo-ocular reflex causes the eyes to drift slowly in one direction and to reset with a corrective fast phase in the opposite direction. This happens because one horizontal canal has an increased firing rate and the brain interprets this as a rotation of the head toward that side. Nystagmus is conventionally named for the direction of its fast phase, whose rules are captured by COWS: Cold-Opposite, Warm-Same. The rapid phase of nystagmus caused by cold irrigation beats away from the stimulated ear (and the slow phase drifts toward it), while that caused by warm irrigation beats toward that ear. Both components ought to be stated explicitly, because the literature that this thesis draws on refers to the direction of the nystagmus as an index of the direction of vestibular activation: a left nystagmus is produced by left-cold or right warm CVS, and a right nystagmus by left warm or right cold CVS (Rubens, 1985; Vallar et al., 1990). This mapping is very important for the neglect and body-representation applications later on, where left-cold CVS-which activates mainly right hemisphere vestibular cortex-is the configuration that temporarily lessens left-sided deficits.

The caloric response exhibits three characteristic features that are relevant to experimental design. Initially, the nystagmus and related sensation of illusory self-rotation and vertigo appear slowly: these effects occur only after around ten to twenty seconds of irrigation, once the thermal gradient has formed. Secondly, the response is fairly sustained, during and to some extent after an irrigation that typically lasts on the order of thirty to sixty seconds. Another feature of the vestibular system is that it adapts to stimulation. During constant-temperature stimulation, for example, the cupula re-equilibrates to its displaced position after a few minutes, afferent firing returns towards tonic baseline, and nystagmus disappears even during continued stimulation (Lopez and Blanke, 2014). The magnitude of the response is clinically assessed from the slow-phase velocity of the nystagmus. Left-right asymmetries are computed by the Jongkees difference-over-sum formula for detecting canal paresis (Lopez and Blanke, 2014).

The mechanism has two caveats that must be noted. Initially, Bárány's thermal-convection explanation has remained the benchmark and is generally employed to elucidate nearly all asymmetrical responses, but it is not without detractors. As noted in the previous chapter, the fact that caloric nystagmus can still occasionally be elicited in microgravity, where convection cannot occur, implies that there are additional factors at work. The subject of caloric nystagmus has also been the subject of several alternative proposals. This debate need not be adjudicated by the thesis, but convection ought not to be portrayed as the only mechanism, settled or otherwise. Moreover, CVS is inherently unilateral and non-specific at the level of the end organ; this is because its delivery is to one ear at a time, which endows it with a strong and useful lateralisation, but within that ear the thermal stimulus does not cleanly isolate a single canal or the otoliths, and the resulting signal is a composite. However, its end-organ non-specificity is a limitation of a different sort that GVS also embodies.

The afferent signal created by CVS passes through the vestibular nuclei and predominantly projects to the opposite hemisphere. Through the cortical vestibular network, it is largely directed towards the parieto-insular vestibular cortex, which helps resolve the uncorrelated vestibular information that earlier chapters identified with the representation of the body. Functional imaging studies have conducted on healthy volunteers indicating that the cognitive and bodily effects of CVS occur following the activation of these cortico-subcortical networks and probably mediated by them, but not merely by oculomotor activity alone. This is important when doing a proper weighing of the "genuinely vestibular versus low-level by-product" debate in the next subsection.

Galvanic vestibular stimulation sends a small direct electrical current, usually in the range of 0.5-5 mA, through an array of surface electrodes placed on the skin over the mastoid processes. Unlike CVS whose action on endolymph and cupula is upstream of hair cells, GVS works directly on the vestibular afferents themselves, modulating firing at the spike-trigger zone directly an way that does not involve mechanical deflection of the cupula. The current's polarity influences the direction of the result: cathodal current depolarizes the afferent trigger site and increases firing, while anodal current hyperpolarizes it and decreases firing (Fitzpatrick & Day, 2004).

Because of the indiscriminate contribution of the current on the afferents, GVS does not cause a selective stimulation of one canal or end organ but modulates the entire afferent population from the labyrinth beneath each electrode more or less together - a key difference in specificity to natural head movement. Fitzpatrick and Day (2004) describe the central problem of GVS as not knowing exactly what input this stimulus delivers to the system despite the fact that the technique is simple, safe, reliable vestibular.

The spatial arrangement of the response produced is determined by the distribution of the electrodes, and three configurations have appeared repeatedly in the literature. The most popular montage is the bipolar montage, whereby the anode is placed over one mastoid and the cathode over the other. The simultaneous inhibition of the anode and the excitation beneath the cathode produces an imbalance between laby- rinthine systems (the two sets of vestibular structures in the inner ear of lower vertebrates), which the CNS interprets as a head movement. The summed signal across all six semicircular canals as specified in the vector model of Fitzpatr ick and Day (2004) is consistent with a virtual head motion that has a large roll component and a smaller yaw component. Both components are directed such that the oculomotor and postural responses it evokes will be oriented toward the anode. Such as the standing participant sways toward the anode, or equivalently, away from the cathode, while the immobilised or seated participant has an illusory roll tilt toward the anode (Cauquil et al., 2000; Fitzpatrick and Day, 2004; Dlugaiczyk et al., 2019). The change of polarity changes the direction, which, together with the near-instantaneous initiation of the electrical effect, gives GVS its characteristic manipulability as an experimental object. The nystagmus eye movement that is associated with the cathode is conventionally horizontal and torsional (Cauquil et al., 2000; Dlugaiczyk et al., 2019).

Used when a different response geometry is required, two further montages. In the binaural (bilateral) monopolar montage, both mastoid electrodes are the same polarity and a distant reference electrode (for example on the forehead) completes the circuit; this leads to the predominant response in the sagittal-plane - a small backward pitch with little or no roll component. In the single channel monopolar montage, one active electrode sits on one of the two mastoids and the reference is placed elsewhere. The result is an oblique, stereotyped sway whose anterior-posterior direction depends on the polarity of the active electrode: if the cathode is the

mastoid, there will be a forward bias in the deviation, if the anode there will be a backward bias. There will also be a lateral component, namely to the anodal side or away from the cathodal side (Cauquil et al., 2000; Dlugaiczyk et al., 2019). The bilateral bipolar montage is the most relevant montage for the body-representation and self-processing questions of this thesis, since it is the one used in the rubber-hand-illusion and ownership studies referenced in earlier chapters.

A key mechanistic point deals with which end organs contribute to the galvanic signal. GVS stimulates both semicircular-canal and otolith afferents because it activates the entire afferent population. The component of evoked virtual motion from canals is adequately characterised by the vector model. However, the otolith component is less clear. Moreover, the weighting of canal versus otolith signals in the percept remains unclear (Reynolds & Osler, 2012). The otolith organs, especially the saccule, were implicated specifically in the earlier chapter's depersonalization findings, thus this matters for the thesis; unlike a targeted otolith test, GVS does not allow that end-organ dissociation.

Bringing together the two descriptions of the mechanisms already anticipate the coming comparison. CVS generates a signal, sufficiently strong and sustained, which is physiologically patterned but develops slowly and can confuse the brain with thermal stimuli. This signal is delivered to one ear at once. GVS generates a signal across the whole population that is weaker and more artificial. Further, this signal can switch on and off within milliseconds, change polarity, set over a range of montages and a credible sham blinding against it. Depending on what a given experiment needs will determine which of these is preferable, but that is a question that does not have a single answer - it is the issue taken up directly in the comparison subsection below.

The temporal profiles of both techniques are also quite different from each other, as are their practical parameters for experimental design. As mentioned earlier, the caloric reaction begins gradually from 10 to 20 secs of irrigation, reaches its peak while the irrigation continues, and then adapts in a few minutes; a single irrigation thus delivers a stimulus epoch in the range of tens of seconds, and the experimenter has little control over its precise onset offset or intensity moment-to-moment. In clinical settings, standard bithermal caloric procedures space out consecutive irrigations by several minutes to let the response subside and to avoid carry-over. Galvanic stimulation defines the electrical parameters specified by the experimenter. Onset and offset are effectively instantaneous. The intensity (typically 0.5-5 mA) and the waveform (constant DC, pulsed, noise) are specified directly. Moreover, it can be sustained as long as it is tolerable, or delivered in precisely timed epochs locked to task events. CVS has no access to this temporal precision which is a GVS experimental benefit.

When procedures are strictly adhered to, both the techniques are considered safe. According to Utz et al. (2010), GVS can be regarded as a specific case of transcranial direct-current stimulation, the only difference being that in GVS, the electrodes are placed at the mastoids. The authors conclude that the safety of both tDCS and GVS is similar at regular intensities. In a dedicated safety study, it was reported that GVS led mostly to minor side effects. These side effects were generally transient and included itching or tingling of the skin under the electrodes, slight nausea, and rare instances of dizziness. These side effects happened to be similar in both stroke patients and healthy participants (Utz et al., 2010). The vestibular effects it intentionally induces are negative effects of CVS; vertigo, an overpowering illusion of self- or world-rotation, and nausea in a large minority; also, cold irrigation is generally more aversive than galvanic stimulation. Caloric irrigation is contraindicated in the presence of a perforated tympanic

membrane or an infected ear. Water irrigation is avoided in such circumstances and air or closed-loop is preferred. In this thesis, the relevant comparison is that GVS is kinder and easier to control than CVS, which delivers a stronger and less pleasant vestibular effect. This difference matters both in terms of participant tolerability and as will be discussed next.

The onset of stimulation is defined by the parameters and occurs nearly instantaneously, allowing it to be time-locked to stimuli or responses, and importantly for controlled designs, it can be administered at imperceptible, subsensory intensity. With this last property, it becomes possible to carry out credible sham control and participant blinding: noisy galvanic vestibular stimulation (nGVS) applied under the cutaneous perceptual threshold can modulate the vestibular system while being consciously undetectable, and sham-stimulation-controlled GVS studies have been conducted on, for example, arm-position sense in spatial neglect (Utz et al. (2010); on the tDCS blinding logic more generally (Gandiga et al. (2006)). In contrast, CVS creates a clear and undeniable sense of dizziness that the participant cannot miss, making it very hard to make a convincing sham condition. This is a serious limitation of any design that wishes to separate specific vestibular effects from expectancy or arousal.

Strength, duration and "physiological" character of the second dimension have the advantage of CVS for the questions of this thesis. CVS generates a powerful and sustained signal which shapes this vestibular input in a way similar to a natural (albeit prolonged) response from the canals and produces a strong and well-lateralized activation of the contralateral vestibular cortical network. It is exactly this strong, sustained, efficient lateralised cortical engagement that made CVS the tool of choice in the neglect and body-ownership literatures (discussed in previous chapters), in which the aim is to up-regulate an under-activated right-hemisphere body

representation for long enough to detect a behavioural change. GVS is not able to produce that kind of sustained representational shift as it exerts a weaker and more transient perturbation.

The third dimension is spatial specificity and interpretability. Here, the picture is mixed rather than clearly favouring one technique. CVS is intrinsically unidirectional, giving it a strongly - and experimentally useful lateralisation - one irrigation preferentially involves one hemisphere. The standard bilateral bipolar montage in GVS is essentially bilateral and as a result creates a more spatially complex and less cleanly lateralised activation pattern. Conversely, the GVS acts directly and predictably on the afferents at a known site. The end-organ composition of the caloric signal is harder to specify. Neither technique can isolate a single canal or the otoliths: CVS delivers a thermal composite and GVS activates the whole afferent population, canal and otolith together, with the otolith contribution to the galvanic percept still incompletely characterised (Reynolds and Osler 2012).

Another issue, fourth and cross-cutting, is the "genuinely vestibular versus low-level by-product" debate; this has particular force in the case of CVS. The ability to create nystagmus in their subjects combined with a predictable directional gaze bias, which was first demonstrated in 1991, raises the age-old question: Do the effects of CVS on spatial cognition, which include for example the amelioration of neglect, reflect a true modulation of our central body- and space-representation or do they merely represent a low-level effect due to shifting our eyes and attention in a particular direction? According to Rubens (1985) in the founding study, the left-cold or right-warm CVS improves left visual neglect. However, the improvement appears to be dependent on the facilitation of leftward gaze because the author framed the effect substantially in their directional nystagmus. Later discoveries provided a more intricate perspective regarding this low-level reading. CVS was demonstrated to have a temporary remission of deficits that do

not clearly rely upon the direction of visual gaze. These include personal neglect, anosognosia, and somatoparaphrenia. Moreover, the imaging involving healthy participants demonstrated that CVS mobilizes cortico-subcortical body-representation networks. It does not act through oculomotor activity alone. The present perspective is that CVS effects are not reducible to eye-movement artefacts. However, the direction of nystagmus is still a useful index of the direction of vestibular activation, and carefully designed experiments must still control for eye-movement (oculomotor) artefacts and attentional confounds. GVS faces a similar challenge as well its ability to sense the stimulation under the electrodes provides a tactile signal and a possible confound but it has greater hold against this objection because it can be applied subsensorily in a sham-controlled manner.

For the specific purposes which predominate this thesis - inducing or restoring sustained, well-lateralised shifts in body-representation and self-experience, as in the neglect, somatoparaphrenia, ownership, and body-temperature studies - CVS is generally the more appropriate tool, as it generates a strong, sustained, physiologically patterned and strongly lateralised signal which reliably engages the right-hemisphere body-representation network. This circumstance should not be overlooked. In addition, GVS have countervailing strengths that are equally real; and which should not be underestimated: superior temporal precision; direct, parameter-defined afferent activation; a variety of montages and gentler tolerability; and, most importantly, the possibility of imperceptible, sham-controlled, properly blinded delivery which CVS cannot easily offer. If an experimental task requires accurate timing or strict blinding, GVS is most suitable. CVS suits experimental tasks that require prolonged and lateralised engagement. The conclusion scoped here is not only more defensible but also more useful than a blanket claim of superiority for either.

The vestibular signal is not something that is a fixed reflex input that is encapsulated within a particular channel. Rather, it is impacted by top-down modulation. This is something that is important to think about both methodologically (for imagine stimulation experiments) as well as theoretically (for predictive-processing), where higher levels expectations shape the treatment of afferent signals. Vestibular stimulation produces an oculomotor response that provides some of the clearest evidence for such cognitive penetrability, and here the distinction between slow and fast nystagmus phases becomes central.

The slow phase is the vestibuloocular output and its speed (slow phase velocity, SPV) is the standard measure of peripheral vestibular drive. However, even during the slow phase, one's central state does not impact this process. It is already known clinically that drowsiness or under-arousal will suppress caloric nystagmus. Hence, during caloric testing, 'alerting' or mental tasking procedures are used to keep the participant alert and not produce an artefactual reduction in SPV (slow-phase velocity). Collins (1963) showed experimentally that manipulations of arousal alter caloric nystagmus, and Kileny et al. (1980) found that attention-requiring tasks modulate the vestibular nystagmic response; more recent videonystagmography work has investigated whether mental tasking measures a change in clinically-critical SPV and found at lEast some evidence that in healthy young adults the effect on SPV itself is limited, even as tasking changes other characteristics of the record (Easterday et al. (2016). The main takeaway for this dissertation is one that any CVS or GVS experiment needs to control for arousal and cognitive engagement, because the vestibular response itself is state-dependent.

The fast phase, being the more cognitively penetrated component, is the most relevant for the present research. The brainstem burst circuitry generates the fast phases, which are saccade-like

resetting movements. Moreover, the paramedian pontine reticular formation and rostral interstitial nucleus of the MLF produce voluntary saccades. Additionally, these fast phases get modulatory inputs from the superior colliculus and cortical gaze centres. Due to the quick phase being linked to the saccadic and attentional-orienting machinery and not being a direct read-out of canal drive, the quick phase is the component most sensitive to attention, cognitive set, and gaze strategy. Nystagmus is conventionally named by the direction of the quick phase. The vestibular ocular response is also subject to top-down control phenomena in two additional cases. Initially, it reduces caloric nystagmus. The suppression of caloric nystagmus is a cerebellar- and pursuit-mediated override. That is the reason why we perform caloric testing in darkness or behind Frenzel lenses and not with fixation. In addition to the above-mentioned ways in which the vestibulo-ocular reflex can be modified, it can also be more dramatically modified by the frame of reference that the participant is imagining. For example, directing attention to an imagined target which is either earth-fixed or chair-fixed will change the eye-velocities elicited by the reflex: in other words, less weight is given to the vestibular signals from the participant's ear and more weight to other higher signals. It is as if higher centres are taking the reflex activity and calibrating it to the spatial frame of the subject, rather than just a dipole formed on vestibular input.

Thus, CVS and GVS are two non-invasive ways to perturb the vestibular signal in an awake human. However, they perturb it differently. CVS drives convection in the horizontal canal via thermal gradient, leading to cupula deflection and modulation of afferent firing (warm excitatory, cold inhibitory), producing a strong, sustained, unilateral and strongly lateralised signal (COWS, fast phase designates the nystagmus). The afferents are directly modulated at the spike-trigger zone (cathodal excitatory, anodal inhibitory), with the montage - bilaterally bipolar most

commonly, and with responses directed towards the anode - that determines the response geometry, and the entire afferent population activated together. According to the author of this thesis, CVS provides superior signal strength, duration, lateralization and the high interpretability of the two methods at least for the purposes of this thesis, while GVS is superior in signal temporal precision and blindness. Top-down modulation influence the vestibular ocular response to both arousal, fixation, attention and cognitive frame of reference. Meanwhile the attention-linked fast phase is the most cognitively penetrated component. Which is evidence, in itself, for the cognitive penetrability of vestibular processing. Caloric stimulation has been primarily used on neurological patients to show the vestibular contribution to body representation, which links interoceptive physiology to the vestibular contribution as a result of coupling ownership restoration to ther regulatory change.

1.7. Nystagmus

The VOR can be considered as a crucial component of caloric vestibular stimulation (CVS) assessment, evaluated post-irrigation as a primary indicator of successful vestibular activation. Under normal conditions, VOR manifests as nystagmus - an involuntary, rhythmic oscillation of the eyes characterized by a slow conjugate deviation in the direction of the induced endolymphatic flow, followed by a fast corrective saccade in the opposite direction. Nystagmus is an involuntary, rhythmic, oscillatory movement of the eyes in which at least one phase is a slow drift (Eggers et al., 2019). It is distinguished from the saccadic intrusions and oscillations (square-wave jerks, ocular flutter, opsoclonus) in which the abnormal movement that takes the eye off target is a fast, saccadic one rather than a slow drift. This definitional detail matters: what makes an eye movement a nystagmus is the presence of a pathological or reflexive

slower phase, and everything else in the taxonomy follows from what that slow phase is doing and whether it is reset by a fast phase. Beyond its diagnostic utility, the VOR has become a valuable research tool for probing the integrity of vestibular function in both clinical and experimental contexts. While horizontal nystagmus is the most commonly observed presentation in caloric testing, the reflex may also present as vertical, rotary, or decelerating oscillations, and in some cases as disconjugate nystagmus, in which the two eyes differ in the direction or magnitude of their oscillatory motion. Two structural forms are generally recognised: jerk nystagmus, which has a slow phase in one direction and a corrective fast phase in the other, producing the characteristic sawtooth waveform; pendular nystagmus, which consists of slow phases only, oscillating symmetrically with no fast-phase reset (Eggers et al., 2019). The first type of nystagmus mentioned is the form most relevant to vestibular function, and is the one to be focused on in this study. In the context of CVS, the elicitation of nystagmus is not indicative of pathology; rather, it reflects the expected physiological response to artificially induced thermal stimulation of the semicircular canals, which generates convection currents within the endolymph and mimics the effect of angular acceleration on the vestibular periphery. Nystagmus is typically expected to onset within 30 seconds of irrigation completion, and is clinically observed by instructing the participant to engage in smooth pursuit of a fixation target, which allows for the reliable detection and characterization of the reflex response.

The two phases of jerk nystagmus are produced by different neural mechanisms, and separating them is the key to understanding the whole phenomenon. The slow phase is the primary event and reflects the underlying drive or defect. In vestibular nystagmus it is generated by the vestibulo-ocular reflex: an imbalance in tonic activity between the two labyrinths (whether from natural head rotation, caloric or galvanic stimulation, or a unilateral lesion) drives a slow, smooth

conjugate drift of the eyes. More generally, the slow phase reflects the state of the gaze-holding and gaze-stabilising circuitry - the peripheral vestibular input, the brainstem "neural integrator," the velocity-storage mechanism, and the cerebellum - and its velocity is the quantity that indexes that drive (Eggers et al., 2019). The shape of the slow-phase waveform is itself diagnostic: a constant-velocity (linear) slow phase produces the sawtooth pattern typical of vestibular or cerebral-hemispheric imbalance, a decreasing-velocity (negative-exponential) slow phase is typical of gaze-evoked nystagmus from a leaky neural integrator, and an increasing-velocity slow phase suggests an unstable integrator (Eggers et al., 2019).

The fast phase is the corrective, resetting event. When the slow drift threatens to carry the eyes toward the edge of their oculomotor range, a rapid, saccade-like flick returns them toward centre. Crucially, the fast phase is generated not by the vestibular system but by the saccadic burst circuitry of the brainstem - the paramedian pontine reticular formation (PPRF) for horizontal movements and the rostral interstitial nucleus of the medial longitudinal fasciculus (riMLF) for vertical and torsional movements - the same premotor machinery that produces voluntary saccades, gated by omnipause neurons (Eggers et al., 2019); classical modelling by Cohen et al. (1981). The relationship between the two phases has been modelled as a relaxation oscillator: velocity information driving the slow compensatory drift is accumulated and used to trigger the saccadic system, which resets the eyes, whereupon the cycle repeats (Cohen et al., 1981). Because the fast phase is produced by the saccadic and gaze-orienting circuitry rather than being a direct read-out of vestibular drive, it is the component most closely tied to attention, arousal, and gaze strategy while the slow-phase velocity remains the purer index of peripheral vestibular function. Not all nystagmus is a sign of disease. Physiological nystagmus is the normal, expected response of a healthy vestibulo-ocular and optokinetic system to appropriate stimulation.

Vestibular nystagmus evoked by head rotation, by caloric or galvanic stimulation, and by sustained rotation (per- and post-rotatory nystagmus) is physiological, as is optokinetic nystagmus (OKN), the slow-pursuit-plus-reset response to a moving visual field, and end-point nystagmus, a few beats of low-amplitude nystagmus at extreme lateral gaze in normal individuals. The caloric and galvanic responses discussed in the preceding chapter fall squarely in this category: the nystagmus they produce is the visible signature confirming that the vestibular system has been engaged, and its slow-phase velocity is used precisely because it quantifies that engagement.

Peripheral vestibular nystagmus - the kind produced by a lesion of the labyrinth or vestibular nerve, and mimicked by unilateral caloric stimulation - has a recognisable profile. It is typically mixed horizontal-torsional and unidirectional, keeping a fixed direction relative to the head regardless of where the eyes look, because it reflects the combined effect of an imbalance across all three semicircular canals on one side (Eggers et al., 2019). It obeys Alexander's law: the nystagmus intensifies when the eyes are directed toward the fast-phase side and diminishes toward the slow-phase side (Robinson et al., 1984). And, most usefully at the bedside, it is suppressed by visual fixation and becomes more prominent when fixation is removed - in darkness, behind Frenzel goggles, or when the fixating eye is covered (Eggers et al., 2019). This last feature, VOR suppression or cancellation, is the ability of healthy visually-mediated tracking to override vestibular slow phases, and its presence marks the nystagmus as peripheral. In an acute unilateral vestibular loss the spontaneous nystagmus beats away from the damaged side (fast phase toward the healthy ear).

Alexander's law deserves a brief mechanistic note because it illustrates how central compensation shapes even peripheral nystagmus. Robinson and colleagues (1984) showed that

the law is not a mechanical property of the orbit but is created centrally: in patients with a vestibular lesion it arises from the summation of the vestibular nystagmus with an abnormally large gaze-evoked nystagmus produced by an adaptively altered neural integrator, such that the drift velocity is reduced in one gaze direction and augmented in the other. The phenomenon is thus a window onto how the nervous system attempts to compensate for a vestibular imbalance. Central vestibular nystagmus, by contrast, breaks these rules. It may be purely vertical (downbeat or upbeat) or purely torsional - patterns that a peripheral lesion does not produce and that therefore localise to the brainstem or cerebellum. It is frequently direction-changing (gaze-evoked in more than one direction), and, critically, it is not suppressed by fixation and may even be enhanced by it (Büttner, Helmchen, & Brandt, 1999; Eggers et al., 2019). Downbeat nystagmus, the most common acquired central form, exemplifies the pattern: a spontaneous downbeating nystagmus in straight-ahead gaze, associated with impaired vertical smooth pursuit, impaired fixation suppression of the VOR, and often gaze-evoked nystagmus, arising typically from lesions of the vestibulocerebellum (the flocculus and parafloccular lobe), whose Purkinje cells normally inhibit brainstem vestibular premotor neurons according to Eggers et al. (2019). The clinical value of these distinctions is considerable: in the acute vestibular syndrome, a spontaneous nystagmus combined with a normal head-impulse test, or a direction-changing gaze-evoked nystagmus or skew deviation, raises suspicion of a central rather than a benign peripheral cause (Eggers et al., 2019).

Another important category is gaze-evoked nystagmus, which appears when the eyes are held in an eccentric position rather than in straight-ahead gaze. Its mechanism is a failure of the neural integrator - the brainstem-cerebellar network (involving the nucleus prepositus hypoglossi, the medial vestibular nucleus, and the cerebellum) that mathematically integrates eye-velocity

commands into the tonic position command needed to hold the eyes against the elastic restoring forces of the orbit. When this integrator is "leaky," the eyes drift back toward centre from an eccentric position (a decreasing-velocity slow phase), and a corrective fast phase brings them back out, producing a nystagmus that beats in the direction of gaze. Gaze-evoked nystagmus is therefore a sign of impaired gaze-holding rather than of vestibular imbalance per se, and its decreasing-velocity waveform distinguishes it from the constant-velocity waveform of vestibular nystagmus (Eggers et al., 2019). The interaction of a leaky integrator with a vestibular lesion is, as noted above, the substrate of Alexander's law.

Related central mechanisms include the velocity-storage mechanism, an indirect vestibular pathway that prolongs and integrates canal signals, extending the duration of the vestibular response beyond the raw canal afferent signal and contributing to per-rotatory and optokinetic after-nystagmus.

Because slow-phase velocity is the quantity that indexes vestibular drive, its measurement is central to clinical and experimental use of nystagmus. Historically, eye movements were recorded by electronystagmography (ENG), which uses the corneoretinal standing potential picked up by periocular electrodes; contemporary practice more often uses videonystagmography (VNG), an infrared video-based method, or, in research settings, the scleral search-coil technique for high-precision three-dimensional recording. From the recorded trace the fast and slow phases are separated - for example by velocity-based clustering - and the slow-phase velocity is quantified. In bithermal caloric testing, the peak slow-phase velocities from each ear and temperature are entered into the Jongkees difference-over-sum formula to yield measures of canal paresis (a left-right asymmetry) and directional preponderance (Jongkees, 1962). Two methodological points from the previous chapter bear repeating here, because they are properties

of nystagmus itself: recording must generally be performed without visual fixation, since fixation suppresses peripheral vestibular nystagmus and would corrupt the measurement; and the participant's arousal must be maintained, since drowsiness suppresses the response, which is why alerting or mental-tasking procedures are used during testing.

To summarise, nystagmus is an involuntary eye oscillation defined by its slow phase, structured in the vestibular case as a slow vestibulo-ocular drift reset by a saccadic fast phase, and named - by convention - for the fast phase. The slow phase, generated by the vestibular and gaze-holding circuitry, is the informative read-out of vestibular drive and the basis of quantitative measurement; the fast phase, generated by the brainstem saccadic burst neurons (PPRF, riMLF), is the resetting movement and the component most tied to attentional and gaze-orienting control. The distinction between physiological nystagmus (the normal response to vestibular or visual stimulation, including the caloric and galvanic responses used as tools in this thesis) and pathological nystagmus, and within the latter between peripheral and central patterns (separable by their trajectory, adherence to Alexander's law, direction-changing behaviour, and - decisively - their suppression or non-suppression by fixation), organises the entire clinical taxonomy. For the purposes of this thesis, nystagmus matters in two ways: as the measurable signature by which caloric and galvanic vestibular stimulation are confirmed and quantified, and - through the fast phase's embedding in the saccadic and attentional circuitry - as one of the clearest illustrations that the vestibular ocular response is open to cognitive and top-down modulation.

1.8. Graphesthesia

Graphesthesia, in classical neurology, refers to the ability to recognise symbols such as letters or numbers that can be traced on the surface of the skin in a clean decipherable manner. Its loss

(agraphesthesia) has long been used as a test of cortical, particularly parietal, somatosensory integration. In the last decade, however, the same basic operation - drawing an ambiguous letter on the body and asking the person what they felt - has been repurposed by Auvray (2019) into something considerably more powerful for the study of the bodily self: a behavioural probe of the spatial perspective from which a person perceives sensations on their own body. It is this reconceived, experimental form of graphesthesia, rather than its clinical ancestor, that is central to the present thesis, because it operationalises - in a simple, quantifiable, non-verbal task - exactly the egocentric-versus-decentred reference-frame question that the vestibular and interoceptive literatures both bear upon. Thus, the the following can be hypothesised: that graphesthesia can serve as an instrument for investigating vestibular contributions to self-perception within the caloric testing paradigm. It will be the main focus of this research to test wether this is a valid hypothesis or the use of such method is not justifiable yet.

The logic of the paradigm rests on the use of mirror-twin tactile symbols. When a letter such as b, d, p, or q is traced on a surface of the body, the letter that the person reports depends on the spatial reference frame they adopt to interpret it, because these four letters are transformations of one another under reflection and rotation (Arnold & Auvray, 2017; Auvray, 2019). Consider a "b" drawn on the abdomen. A person adopting an egocentred-trunk perspective - reading the letter as though looking down at their own torso - reports the mirror-reversed "d"; a person adopting an egocentred-head perspective - mentally rotating the head forward to "look at" the stomach, a 180° transformation - reports "q"; and a person adopting a decentred perspective - as if reading the letter from an external vantage point facing them - reports "b" (Arnold & Auvray, 2017; Auvray, 2019; Baiano et al., 2021, 2023). Crucially, none of these responses is an error in

the ordinary sense; each is the correct answer given a particular perspective, so the letter the person reports is a direct read-out of the reference frame they spontaneously adopted.

This is the feature that makes graphesthesia so valuable. Rather than asking people to introspect on their point of view, the task infers it objectively from performance, and it does so on the person's own body, using tactile stimulation, so the perspective in question is genuinely a bodily one rather than a judgement about an external visual scene. Modern implementations deliver the letters through a small array of vibrators placed on the body (typically the abdomen), with each letter presented via a timed sequence of vibrations (Arnold & Auvray, 2017; Auvray, 2019; Baiano et al., 2021, 2023). Two kinds of measure are extracted: in a free session the person recognises letters with no instruction, revealing which perspective they spontaneously prefer and how consistently they use it; in an imposed session a cue specifies which perspective to adopt on each trial, so that the cost of switching between egocentred and decentred frames - the flexibility of perspective-taking - can be quantified from accuracy and reaction time (Baiano et al., 2023). Across studies a majority of participants spontaneously adopt an egocentred perspective, most often trunk-centred; for example, Baiano et al. (2023) found roughly 58% egocentred-trunk, 15% egocentred-head, and 27% decentred, with a reliable switch cost when participants had to leave their preferred egocentred frame.

The theoretical interest of the paradigm follows from a broader position: that spatial perspective-taking - mentally displacing the self into a new position and orientation - is an embodied process, drawing on motor and somatosensory representations of the body rather than on abstract spatial computation alone. Kessler and Thomson (2010) showed that taking a spatial perspective on an external scene involves emulating the body movements that would be required physically to occupy the new viewpoint. Arnold and Auvray (2017) extended precisely this logic to the body

itself using graphesthesia, showing that adopting a head-centred perspective on a bodily surface is constrained by the physical possibility and extent of the head movement that would be needed to look at that surface: recognition was easier when the required mental rotation of the head corresponded to a physically possible movement than to an impossible one, and performance declined as the amount of bodily movement needed to rotate the head toward the stimulated surface increased. Head-centred perspective-taking, in other words, is not a free mental rotation but a simulated bodily action.

This embeds graphesthesia firmly within the framework of bodily self-consciousness that earlier chapters developed. On Blanke's (2012) account, the ordinary first-person perspective - experiencing the world from within one's body - is a core component of bodily self-consciousness, constructed from the integration of multisensory bodily signals. The egocentred perspective measured by graphesthesia is that first-person, body-anchored perspective; the decentred perspective is its relaxation, a mental adoption of an external or other-centred viewpoint. The task therefore provides a behavioural window onto the very reference frame that anchors the self to the body, and onto the flexibility with which that anchoring can be loosened - which is exactly the variable that vestibular and interoceptive signals are theorised to influence.

The claim that graphesthesia indexes an embodied reference frame is not merely interpretive; there is direct evidence that manipulating or measuring bodily afferent signals changes the perspective people adopt on the task. This evidence is the empirical backbone of the thesis's hypothesis, because it establishes the general principle that graphesthesia performance is sensitive to bodily input.

The clearest causal evidence comes from somatosensory manipulation. Arnold and Auvray (2017) and Auvray (2019) tested rare, well-characterised deafferented patients who have lost

tactile and proprioceptive perception below the head, and found that the absence of somatosensory input altered the perspective adopted on the graphesthesia task relative to controls: without bodily afferent signals to anchor a self-centred frame, patients' adopted perspective was less tied to their physical body, and they relied on more idiosyncratic strategies. The manipulation of a bodily afferent stream, in other words, shifts the egocentred/decentred balance. Visual signals likewise shape the adopted frame (Arnold & Auvray, 2017; Auvray, 2019; Baiano et al., 2021, 2023), consistent with the multisensory character of the underlying reference frame.

Most directly relevant to this thesis is the evidence linking interoception to graphesthesia performance. Baiano et al. (2021) had ninety participants complete the graphesthesia task alongside multiple dimensions of interoception (cardiac interoceptive accuracy via heartbeat counting, metacognitive interoceptive awareness, and interoceptive sensibility via the MAIA-2). They reported two key relationships. First, higher cardiac interoceptive awareness predicted greater consistency in adopting a decentred perspective - the more attuned people were to their own cardiac signals, the more stably they could take an external viewpoint. Second, higher cardiac interoceptive accuracy predicted slower and less accurate switching from a decentred back to an egocentred perspective - that is, people with more accurate interoception found it harder to return to their own bodily viewpoint once they had left it. The authors interpret this as reflecting a sharper, less malleable boundary between the internal bodily self and the external world in people with stronger interoception.

For the argument of this thesis, the Baiano et al. (2023) result is interesting in two ways. It establishes graphesthesia as a task on which interoceptive signals - the thesis's home domain - demonstrably modulate the bodily reference frame; and it thereby provides the closest existing

precedent for using graphesthesia as a readout of a bodily contribution to self-perception. It also, however, marks the boundary that no study has yet tested - whether manipulating a bodily signal that converges with interoception - namely the vestibular signal - changes graphesthesia performance. That gap is where this thesis is positioned.

The central hypothesis of this thesis is that graphesthesia can serve as an appropriate behavioural tool to test vestibular contributions to self-perception - specifically, that experimentally perturbing the vestibular signal, by caloric or galvanic stimulation, will shift the egocentred/decentred balance and the flexibility of perspective-taking on the graphesthesia task. It is important to state clearly that this is a proposed use of the paradigm: to the author's knowledge, no published study has combined vestibular stimulation with graphesthesia, and the hypothesis is therefore a contribution of this thesis rather than an established finding. Its motivation, however, rests entirely on findings that are established, drawn together from the preceding chapters.

The motivating chain is as follows. First, graphesthesia indexes the egocentred versus decentred reference frame for perceiving one's own body, and that reference frame is sensitive to bodily afferent input, as the somatosensory (Arnold & Auvray, 2017; Auvray, 2019), visual (Baiano et al., 2021), and interoceptive (Baiano et al., 2023) evidence shows. Second, the vestibular system is a core contributor to exactly this kind of spatial reference frame and to the anchoring of the self to the body: vestibular signals provide the egocentric frame within which other spatial information is interpreted, vestibular stimulation anchors the self to the body (Ferrè et al., 2014), and vestibular signals have been shown directly to influence spatial perspective-taking. Third, as the neglect and somatoparaphrenia literature reviewed earlier demonstrates, caloric vestibular stimulation can shift the egocentric spatial frame of reference - the Bottini and Salvato work

showed left-cold CVS transiently realigning a distorted body-centred frame and restoring limb ownership. Putting these together yields a strong and testable prediction: because vestibular stimulation moves the egocentric reference frame, and because graphesthesia reads out that frame, vestibular stimulation should measurably shift graphesthesia performance - for instance, biasing the spontaneously adopted perspective, or altering the cost of switching between egocentred and decentred frames.

If borne out, this would make graphesthesia a uniquely suitable instrument for the thesis's larger question. It is non-verbal, quantitative, and administered on the participant's own body through touch, so it measures a genuinely bodily self-perspective rather than a judgement about external space; it dissociates egocentred from decentred framing on a trial-by-trial basis, giving a graded, sensitive dependent measure; and it has already been validated as sensitive to somatosensory, visual, and interoceptive input, so a vestibular effect would slot into an established pattern rather than standing alone. Pairing graphesthesia with caloric or galvanic stimulation would thus allow a direct behavioural test of whether the vestibular sense contributes to the reference frame that anchors the self - and, given the demonstrated coupling of vestibular and interoceptive processing at the insular convergence zones discussed throughout this thesis, would provide a route to probing the vestibular-interoceptive contribution to self-perception in a single, tractable task.

Several qualifications keep the hypothesis appropriately bounded. The predicted direction of a vestibular effect is not fixed a priori: vestibular stimulation might strengthen the egocentric anchoring of the self (making the egocentred perspective more dominant or harder to leave), or, by introducing a perturbing signal that loosens body-centred integration, might facilitate decentred framing; the two possibilities correspond to different roles for the vestibular signal and

are themselves worth distinguishing empirically. The laterality of caloric stimulation (left-cold versus right-warm, and their right- versus left-hemisphere engagement) may interact with the left-right structure of the graphesthesia letters, which must be controlled carefully. The interpretive debate around vestibular stimulation rehearsed in the previous chapter applies here too: any graphesthesia effect must be shown to reflect a genuine shift in the bodily reference frame rather than a low-level consequence of nystagmus, gaze bias, or arousal, which argues for including appropriate control conditions and, where possible, the sham-controllable galvanic technique. And because the interoceptive precedent (Baiano et al., 2023) is correlational, the causal, stimulation-conditioned test proposed here would extend that literature rather than simply confirming it.

Chapter 2: Methods

2.1. Participants

Sixteen volunteering students took part in this experiment (11 females and 5 males, M= 24.9, SD= 1.91), with one participant being excluded from the study due to their absence on the second testing session. All subjects but one were right-handed, and have completed the 3-year bachelor's degree cycle. The recruitment was performed digitally via university mailing list. The email contained the advertising text , which included the type of testing to be performed, the expected duration of both sessions, the name of the researcher, and the contact email address. The scheduling process was controlled by the researcher and coordinated accordingly with the laboratory's shared Google Workspace calendar. All willing test subjects were informed about the expected side-effects of CVS, non-invasiveness of the caloric stimulation to be performed, and last but not least - their right to withdraw at any point during the testing procedure.

2.2. Materials and tools

The caloric stimulation of the inner ear required demineralised irrigation fluid purchased from the nearest pharmacy and a syringe with a silicone tube for controlled irrigation, the sanitising liquid and paper towels (which proved to be indispensable for a safe CVS procedure). In order to minimise the discomfort from caloric stimulation, a clean towel was used to absorb the liquid that would be escaping from the ear. Additionally, participants were offered cotton swabs (Q-tips) before the stimulation of the inner ear and, once more, at the end of the experiment.
The Beck Depression Inventory (BDI; Beck, Ward, Mendelson, Mock, & Erbaugh, 1961) was used to assess the severity of depressive symptomatology (see appendix 1). The State-Trait Anxiety Inventory (STAI Form Y; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983) was administered to assess both state and trait anxiety, comprising two 20-item subscales (see

appendix 2 & 3). The Multidimensional Assessment of Interoceptive Awareness, Version 2 (MAIA-2; Mehling, Acree, Stewart, Silas, & Jones, 2018) was used to assess interoceptive awareness across eight dimensions: Noticing, Not-Distracting, Not-Worrying, Attention Regulation, Emotional Awareness, Self-Regulation, Body Listening, and Trusting (see appendix 4).

2.3. Design

All experiment subjects were accommodated at Dr. Bottini's office for the duration of experiment in an effort to maintain control over surroundings and exclude any possible distractions or biases, which could negatively impact the consistency within the data collection. In total, there were two sessions per subject, with randomised administration of caloric test or its SHAM version as a control measure. The first session included: a brief presentation of materials and tools to be used (for obtaining genuine informed consent to CVS); self-administered written questionnaires that were printed out with the laboratory printer beforehand. (STAI, BDI, MAIA); administration of caloric testing/SHAM to the left ear; nystagmus check; graphesthesia test. The second session included: administration of caloric testing/SHAM to the left ear; nystagmus check; graphesthesia test. The researcher was responsible to provide the irrigation liquid of the right temperature corresponding to each of the planned sessions. For the actual CVS, additional cooler bag with ice was prepared beforehand to keep the liquid within range of 0-4 degrees Celcius. A thermometer spoon was used prior the start of the experiment and before each irrigation for verifying the temperature. The nystagmus check was performed with the use of a common pencil devoid of any decorative details. The tracing of the letters for the graphesthesia

task was performed with the use of pointed make-up brush, which was chosen for a more controlled and consistent application.

2.4. Procedure

Upon successful completion of the written questionnaires, participants were instructed to tilt their head on a 30 degrees angle and position a clean towel around their neck in a manner that would prevent any leakage of the liquid that was expected to escape from the ear canal during caloric testing. Each participant was reminded of the fact that they had the right to stop at any given moment, should the need arise. When the irrigation was complete, the used towel was taken aside, and the participants were allowed to return their heads to a natural position for the nystagmus check.

Then, the subjects were instructed to keep their head in a straight position (facing the researcher) and to lock their sight on the focus object (FO), following its motions only with their eyes. After receiving confirmation that instructions were understood, the FO would be used as a pendulum to be methodically swayed from right to left on a horizontal pane. After registering the presence or (intended) absence of VOR, the experiment would be concluded with the graphesthesia testing. Due to the nature of the CVS and the possible occurrence of vertigo the participants were verbally questioned about their current well-being.

At this final stage, participants were instructed to secure a comfortable seated position and keep their eyes closed for the entire duration of the graphesthesia task. Tracing of each letter initiated either with a straight stroke or circular motion – a necessary variation to avoid unwanted pattern guessing from participants. In consideration with the novelty of such stimulation, each session began with a trial of 8 symbols that were traced in a random order. After familiarisation with tactile stimuli has been complete, the actual graphesthesia testing would begin, with participants

being asked participants to name their guesses as soon as the tactile sensation became identifiable as a particular alphabetic symbol to them. In an effort to standardise the administration of the stimuli, central area of the forehead was visually divided by a researcher into a four-sector-square (Fig. 1). Each response was categorised as either first-person perspective (b=d), third-person perspective (b=b) or an error (b=q, b=p, b=etc.).

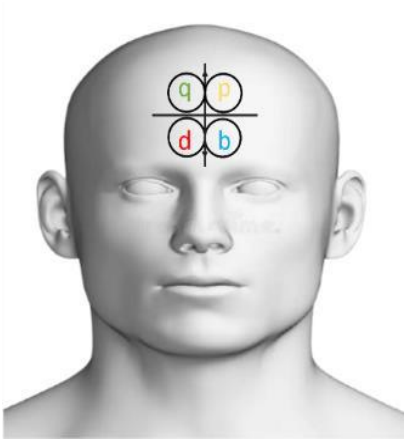

Figure 1. Visualised scheme of how the forehead are was divided into a grid, that was mentally projected onto participants by the researcher during the tracing stage of the Graphesthesia test.

After completion of the tracing of 40 alphabetic symbols participants was offered Q-tips to remove the remaining liquid in their ears. Finally, each subject was thanked by the researcher for their cooperation in the study and was scheduled for their second session within the following two weeks.

Chapter 3: Results

Data analysis was conducted with R (see appendix 5) via RStudio (version 4.5.2; R Core Team, 2025) as the integrated development environment. Data organisation was performed using the tidyverse collection of packages (version 2.0.0; Wickham et al., 2019), including dplyr for data filtering and summarisation, tidyr for conversion between wide and long data formats, and readr for data import. Descriptive statistics, normality testing, and non-parametric inferential tests (Shapiro-Wilk, Friedman) were all computed using the rstatix package (version 0.7.3; Kassambara, 2026). Effect sizes for paired comparisons, including Cohen's d, were calculated with the effectsize package (version 1.0.1; Ben-Shachar, Lüdecke, & Makowski, 2020). Statistical power for the paired-samples t-test was estimated with the pwr package (version 1.3.0; Champely, 2020). Correlation matrices were created by using the Hmisc package (version 5.2.5; Harrell, 2023) and visualised as hierarchically ordered correlograms using ggcorrplot (version 0.1.4.1; Kassambara, 2023). All other data visualisations, including boxplots and Q-Q plots, were generated using ggplot2 (version 4.0.1; Wickham, 2019). The code used for the statistical analysis was based on the R tutorials found on youtube together with an online guideline for psychology students (Danielle Navarro, 2019).

Sixteen volunteering students took part in this experiment (11 females and 5 males, M= 24.9, SD= 1.91). All subjects but one were right-handed, and have had completed the 3-year Bachelor degree cycle. A paired-samples t-test of CVS scores (M = 0.39, SD = 0.23) differed significantly from SHAM scores (M = 0.29, SD = 0.26), $t(15) = 3.30$, $p = .005$. Cohen's d was 0.83. A post-hoc power analysis indicated $1 - \beta = 0.87$ for $n = 16$.

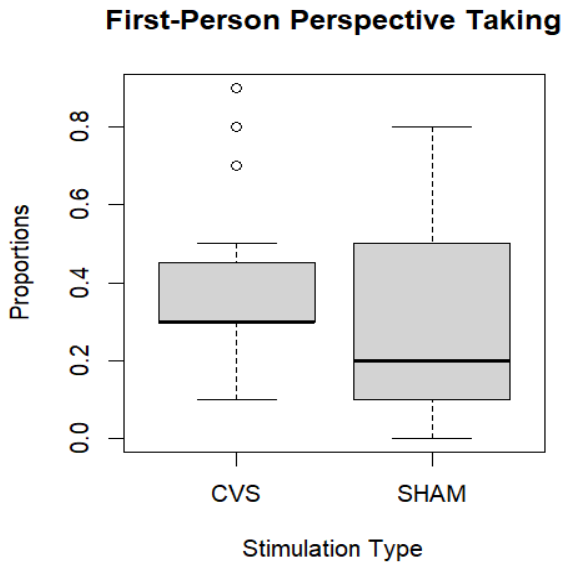

Figure 2| Distribution of First-Person Perspective-Taking Scores under CVS and SHAM

Boxplots for both conditions showed deviations from normal distribution (Fig. 2), which were confirmed by Shapiro-Wilk tests (CVS: $W = 0.81$, $p = .003$; SHAM: $W = 0.88$, $p = .041$). Q-Q plot (Fig. 3) showed a higher median 1PPT score in the CVS condition relative to SHAM, with outliers present in the CVS distribution and absent in the SHAM distribution. Alternatively, a Friedman test was conducted, yielding $\chi^2(1) = 8.07$, $p = .005$. Kendall's W was 0.50.

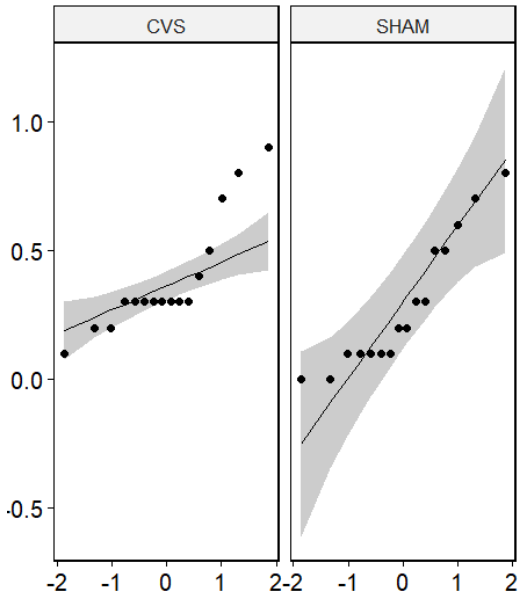

Figure 3| Q-Q Plots of First-Person Perspective-Taking Scores under CVS and SHAM

Pearson correlation matrices were computed for both first and third person perspective taking between CVS(Fig. 4a) and SHAM(Fig. 4b) scores and a set of demographic and psychometric variables, including Age, BDI, STAI-S, STAI-T, and the interoceptive sensibility subscales (Noticing, Not-Distracting, Not-Worrying, Attention Regulation, Emotional Awareness, Self-Regulation, Body Listening, and Trusting).

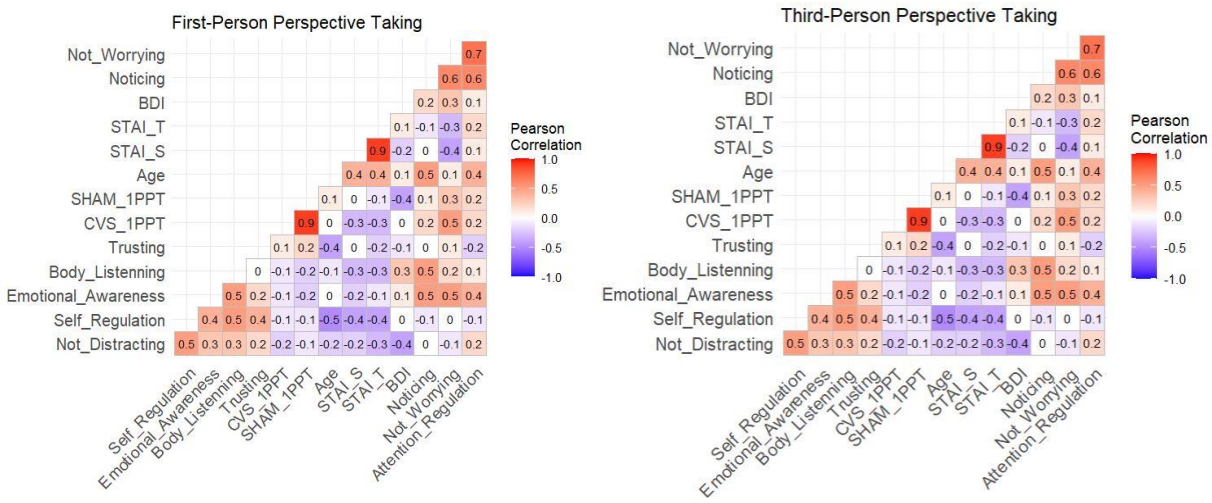

Figure 4| Correlogram of the CVS and SHAM conditioned perspective-taking scores and psychometric variables. a) First-person perspective taking correlation matrix; **b)** Third-person perspective taking correlation matrix.

CVS and SHAM scores for the first-person perspective taking were correlated at r = 0.88. CVS (1PPT) correlated with STAI-S at r = -0.27 and with STAI-T at r = -0.31; SHAM (1PPT) correlated with STAI-S at r = -0.01 and with STAI-T at r = -0.14. CVS (1PPT) correlated with Not-Worrying at r = 0.49; SHAM (1PPT) correlated with Not-Worrying at r = 0.31. CVS (1PPT) correlated with BDI at r = -0.04; SHAM (1PPT) correlated with BDI at r = -0.41. The remaining variables showed correlations of $r \leq |0.3|$ with both CVS and SHAM first-person perspective taking scores.

Third-person perspective taking CVS and SHAM scores were correlated at r = 0.91. CVS (3PPT) correlated with Not-Worrying at r = -0.46; SHAM (3PPT) correlated with Not-Worrying at r = -0.39. CVS (3PPT) correlated with STAI-S at r = 0.21 and with STAI-T at r = 0.21; SHAM (3PPT) correlated with STAI-S at r = 0.02 and with STAI-T at r = 0.12. CVS (3PPT) correlated with BDI at r = 0.08; SHAM (3PPT) correlated with BDI at r = 0.39. The remaining variables showed correlations of $r \leq |0.3|$ with (3PPT) scores in both conditions.

Chapter 4: Discussion

This study showed a significant increase in first-person perspective-taking performance under CVS, compared to the SHAM condition, with a large effect size (Cohen's d = 0.83) and sufficient power. This result is consistent with the previous works (Ferrè et al., 2014; Pavlidou et al., 2017) indicating vestibular contributions to the building and updating of egocentric spatial representations, and provides an extension into tactile-interpretation, measured here by the ability to mentally rotate letters to match the perspective of the researcher. The correlation between 1PPT performance and anxiety scores (STAI-S: r = -0.27, STAI-T: r = -0.31) was observed under CVS but SHAM stimulation did not prove to have a similar effect (STAI-S: r = -0.01, STAI-T: r = -0.14). While anxiety often induces heightened bodily awareness, it is not associated with accuracy of interpretation of bodily signals (Ironside et al., 2023). Under CVS, the additional vestibular signal may compete for the attentional resources required for the perspective-taking task, and such effect is not expected with SHAM, since there is no stimuli involved. Furthermore, SHAM was more negatively correlated with BDI scores (1PPT: r = -0.41, 3PPT: r = 0.39). As reported in previous literature, changes in body self-representation, interoception and sense of agency have been associated with depression (Davey & Harrison, 2022), although this particular relation was not directly investigated in the present study. These results can be considered not significant given the sample size and the likelihood that the participants were sufficiently familiar with the inventories used. Not-Worrying was negatively correlated with 1PPT and 3PPT. Higher levels of not-worrying were associated with better performance on the 1PPT in both conditions but worse performance on the 3PPT. One possible explanation is that egocentric and allocentric perspective-taking place different demands on

attention to internal states, such that reduced focus on bodily sensation may be more compatible with an egocentric rather than an allocentric task. However, this is only a speculation, and it is not directly examined by the present data. The correlation between Not-Worrying and CVS (1PPT) performance was the only MAIA subscale to show a moderate association with task performance; the remaining subscales showed negligible correlations. Not-Worrying reflects a metacognitive rather than perceptual component of interoceptive sensibility, and its association with 1PPT was present only under CVS.

Specifically, the selectivity of this CVS enhancement to first-person perspective taking (and its absence with 3PPT) suggests that CVS is selectively impacting on the self-referred component of spatial cognition. This distinction has theoretical significance for our understanding of vestibular contributions to body awareness. The CVS-conditioned perspective taking results of this study are consistent with the hypothesis that artificially intensifying vestibular input with CVS temporarily amplifies this sense of self in space, resulting in a more frequent first-person perspective taking during graphesthesia testing. While CVS reliably facilitated 1PPT performance, no comparable effect was seen for 3PPT. In addition, correlations between the psychometric variables and tactile perception performance significantly differed across 1PPT and 3PPT. This discrepancy is consistent with evidence for partially separate neural underpinnings of egocentric and allocentric spatial representations; egocentric representations have been shown to depend more strongly on contributions from the somatosensory and vestibular systems (routed primarily through the posterior insular cortex and temporoparietal junction, compared to allocentric representations (more reliant on hippocampal-based circuitry fed by visual input). It is likely that this separation is driven by distinct processes that may be amplified or disrupted by CVS. It is argued that due to selective activation of TPJ from vestibular stimulation, CVS

preferentially benefits the egocentric aspect of spatial cognition, potentially at the expense of independently of allocentric representations. However, a claim as such goes beyond the scope of this study. Recent advances in robotic and technological methodologies have allowed for more extensive studies on the role of the vestibular system in the egocentric spatial representations held by human mind. The use of neuroimaging techniques such as EEG, fMRI, and others to directly observe the effects of caloric stimulation of the vestibular system relative to contributions of the TPJ during egocentric versus allocentric processing is desirable for future studies.

The higher frequency of first-person perspective taking under the influence of CVS, contrasted with 3PPT, is consistent with the hypothesized role of vestibular input in the stabilisation of egocentric spatial representations through its interactions with interoceptive and proprioceptive signals. Rather than a general improvement of spatial cognition, CVS appears to act on the self-referential component of perspective-taking. The results are in agreement with previous works focusing on vestibular function and its possible extension beyond spatial orientation and postural control (Ferrè et al., 2014; Pavlidou et al., 2017; Salvato et al., 2019; De Maio et al., 2021), with vestibular system being involved in the multisensory model of self perception, as well as maintenance of an internal map of the body associated with interoception, risk-taking, strategic behaviour, and more. Using nystagmus as a measure of effective vestibular stimulation and CVS as the experimental approach places the present study within an established methodological framework that uses caloric stimulation to study vestibular effects on perception and cognition. The graphesthesia task is novel in its specific application to perspective-taking, but extends upon this framework by operationalising egocentric and allocentric spatial frames utilising a tactile rather than visual or postural paradigm, differentiating it from more prevalent measures used in

this field. Overall, the present results are consistent with a role for vestibular input in maintaining a model of the bodily self that extends beyond classical visuo-vestibular function, and support the use of CVS as a tool for investigating vestibular contributions to clinical deficits as well as interoceptive bodily self-representation. The interpretations given shall be considered exploratory, considering the limitations of the study described below.

Chapter 5: Limitations

The most obvious limitation of this study is the small sample size (N = 16), which sets limits on the statistical power of the correlation analyses. The primary comparison of CVS vs. SHAM was adequately powered given the observed effect size, but the correlations presented here should be viewed as preliminary observations rather than definitive findings. Therefore, a careful consideration should be taken when interpreting any conclusions drawn from them. The strength of these relationships to be tested in the future would be dependent on a larger sample.

Another issue is the composition of the sample, which was mainly composed of psychology students. Participants were likely familiar with the instruments like BDI, STAI, and MAIA-2 used in this research in connection with either studying or participating in other psychological studies before. Familiarity with an instrument is known to affect responses either consciously or subconsciously, depending on the participant's attempt to manage impressions or his/her expectations regarding "correct" answers. Underreporting of depression symptoms in BDI is a possible example. In view of the fact that no measures could have been taken in order to avoid this problem, future research would benefit from screening participants from other disciplines and/or unfamiliar with Beck's depression inventory. Yet another potential problem is the use of caloric stimulation only for the left ear of all participants. Hemispheric asymmetry in vestibular processing is a well-known phenomenon when the left ear stimuli are processed by the right hemisphere due to the crossing of neural pathways. It might introduce bias due to possible differences between the right and left hemispheres' contributions in tactile discrimination tasks. Future studies will need to overcome this problem.

In addition to that, the graphesthesia task used to measure egocentric and allocentric perspective-taking lacks a formal validation and there is no information regarding the reliability and

construct validity of the procedure. Performance of this task can have been affected by uncontrolled variables such as tactile acuity, visuo-motor coordination and attention control. In future research, test-retest reliability and convergent validity should be checked using existing measures of perspective-taking.

The role played by TPJ and posterior insula in this process cannot be confirmed without neuroimaging data since only behavioral data were obtained. Although the latter seem to confirm this hypothesis, they do not provide any direct evidence about it. Similarly, the possible mediating effect of depression and anxiety on bodily self-representation cannot be tested without neuroimaging or mood manipulation in an experimental setting; mood state, but not trait, measures of anxiety and depression might be better suited for this purpose.

Additionally, the use of self-reports to measure interoceptive sensibility and negative affect comes with several acknowledged limitations such as demand characteristics and response bias, as well as a known dissociation between interoceptive awareness and accuracy.

The decreased association between BDI and the CVS effect on our measure of perspective taking offers one possible direction for studying the potential influence of vestibular stimulation in mood-related contexts. Yet, it is necessary to conduct clinically-controlled experiments on populations that experience self-disorders and have altered interoception to pursue it further.

It would be desirable to conduct replicable studies on a larger sample and employ neuroimaging methods like fMRI or EEG, which would facilitate studying of the neural circuitry involved in perspective-taking processes within CVS. It will be possible to examine the extent to which the vestibular pathway connects to the posterior insula and TPJ. The correlation of functional activation of these areas with behavioral performance could serve as a valuable addition to further studies. Hemispheric asymmetry in the processing of vestibular stimuli can be considered

an important extension in this framework. More research is necessary to validate the use of a graphesthesia test in perspective taking studies. Particularly, it is vital to estimate the test-retest reliability and correlation with established measures of perspective-taking.

Chapter 6: Conclusion

The present thesis examined whether caloric vestibular stimulation influences the spatial perspective adopted during graphesthesia. The central finding was that CVS produced a statistically significant increase in first-person perspective-taking, with no comparable effect for SHAM conditioning. This dissociation suggests that vestibular input does not enhance spatial cognition in general, but acts selectively on the egocentric component of bodily self-perception. The results of this study are consistent with the theoretical position developed across the introductory chapters. In this respect, the study supports the use of graphesthesia as a valid instrument in interoception research employing CVS - with the important qualification that its psychometric properties, namely test-retest reliability and convergent validity against established perspective-taking measures, remain to be formally established before it can be adopted more widely.

The correlational analyses, exploratory in nature given the sample size, produced several observations worth noting. The moderate negative correlations between CVS 1PPT performance and both state and trait anxiety emerged specifically under CVS and not under SHAM, suggesting that the relationship between anxiety and egocentric perspective-taking may be context-dependent, arising under conditions of amplified vestibular input rather than reflecting a stable trait. The attenuation of the BDI association under CVS, observed across both 1PPT and 3PPT, is consistent with the literature linking depression to disrupted bodily self-representation, though it should be treated with caution given the sample and the likelihood that participants were familiar with the instruments used. The reversal of the Not-Worrying association between 1PPT and 3PPT points to a potentially meaningful difference in the cognitive demands of the

two perspective-taking modes, and to the relevance of metacognitive interoceptive processing to how the self is spatially situated. However, that is a question that goes beyond what the present data can resolve. The present results do suggest that when vestibular input is manipulated, the boundary between self and world shifts in a way that is measurable at the level of behaviour, and that graphesthesia may constitute a viable mean of capturing that. Where precisely that boundary lies, and what determines its position, remains open - and it is toward that larger question that this thesis has aimed to make a modest contribution.

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Appendix

A.1. The Beck Depression Inventory

This depression inventory can be self-scored. The scoring scale is at the end of the questionnaire.

1.
- 0 I do not feel sad.
- 1 I feel sad
- 2 I am sad all the time and I can't snap out of it.
- 3 I am so sad and unhappy that I can't stand it.

2.
- 0 I am not particularly discouraged about the future.
- 1 I feel discouraged about the future.
- 2 I feel I have nothing to look forward to.
- 3 I feel the future is hopeless and that things cannot improve.

3.
- 0 I do not feel like a failure.
- 1 I feel I have failed more than the average person.
- 2 As I look back on my life, all I can see is a lot of failures.
- 3 I feel I am a complete failure as a person.

4.
- 0 I get as much satisfaction out of things as I used to.
- 1 I don't enjoy things the way I used to.
- 2 I don't get real satisfaction out of anything anymore.
- 3 I am dissatisfied or bored with everything.

5.
- 0 I don't feel particularly guilty
- 1 I feel guilty a good part of the time.
- 2 I feel quite guilty most of the time.
- 3 I feel guilty all of the time.

6.
- 0 I don't feel I am being punished.
- 1 I feel I may be punished.
- 2 I expect to be punished.
- 3 I feel I am being punished.

7.
- 0 I don't feel disappointed in myself.
- 1 I am disappointed in myself.
- 2 I am disgusted with myself.
- 3 I hate myself.

8.
- 0 I don't feel I am any worse than anybody else.
- 1 I am critical of myself for my weaknesses or mistakes.
- 2 I blame myself all the time for my faults.
- 3 I blame myself for everything bad that happens.

9.
- 0 I don't have any thoughts of killing myself.
- 1 I have thoughts of killing myself, but I would not carry them out.
- 2 I would like to kill myself.
- 3 I would kill myself if I had the chance.

10.
- 0 I don't cry any more than usual.
- 1 I cry more now than I used to.
- 2 I cry all the time now.
- 3 I used to be able to cry, but now I can't cry even though I want to.

11.
0 I am no more irritated by things than I ever was.
1 I am slightly more irritated now than usual.
2 I am quite annoyed or irritated a good deal of the time.
3 I feel irritated all the time.

12.
0 I have not lost interest in other people.
1 I am less interested in other people than I used to be.
2 I have lost most of my interest in other people.
3 I have lost all of my interest in other people.

13.
0 I make decisions about as well as I ever could.
1 I put off making decisions more than I used to.
2 I have greater difficulty in making decisions more than I used to.
3 I can't make decisions at all anymore.

14.
0 I don't feel that I look any worse than I used to.
1 I am worried that I am looking old or unattractive.
2 I feel there are permanent changes in my appearance that make me look unattractive
3 I believe that I look ugly.

15.
0 I can work about as well as before.
1 It takes an extra effort to get started at doing something.
2 I have to push myself very hard to do anything.
3 I can't do any work at all.

16.
0 I can sleep as well as usual.
1 I don't sleep as well as I used to.
2 I wake up 1-2 hours earlier than usual and find it hard to get back to sleep.
3 I wake up several hours earlier than I used to and cannot get back to sleep.

17.
0 I don't get more tired than usual.
1 I get tired more easily than I used to.
2 I get tired from doing almost anything.
3 I am too tired to do anything.

18.
0 My appetite is no worse than usual.
1 My appetite is not as good as it used to be.
2 My appetite is much worse now.
3 I have no appetite at all anymore.

19.
0 I haven't lost much weight, if any, lately.
1 I have lost more than five pounds.
2 I have lost more than ten pounds.
3 I have lost more than fifteen pounds.

20.
0 I am no more worried about my health than usual.
1 I am worried about physical problems like aches, pains, upset stomach, or constipation.
2 I am very worried about physical problems and it's hard to think of much else.
3 I am so worried about my physical problems that I cannot think of anything else.

21.
0 I have not noticed any recent change in my interest in sex.
1 I am less interested in sex than I used to be.
2 I have almost no interest in sex.
3 I have lost interest in sex completely.

A.2. The State Anxiety Inventory

SELF-EVALUATION QUESTIONNAIRE STAI Form Y-1

Please provide the following information:

Name_____Date_____S_____

Age_____ Gender (*Circle*) **M** **F** T_____

DIRECTIONS:

A number of statements which people have used to describe themselves are given below. Read each statement and then circle the appropriate number to the right of the statement to indicate how you feel *right* now, that is, *at this moment*. There are no right or wrong answers. Do not spend too much time on any one statement but give the answer which seems to describe your present feelings best.

	NOT AT ALL	SOMEWHAT	MODERATELY SO	VERY MUCH SO
1. I feel calm	1	2	3	4
2. I feel secure	1	2	3	4
3. I am tense	1	2	3	4
4. I feel strained	1	2	3	4
5. I feel at ease	1	2	3	4
6. I feel upset	1	2	3	4
7. I am presently worrying over possible misfortunes	1	2	3	4
8. I feel satisfied	1	2	3	4
9. I feel frightened	1	2	3	4
10. I feel comfortable	1	2	3	4
11. I feel self-confident	1	2	3	4
12. I feel nervous	1	2	3	4
13. I am jittery	1	2	3	4
14. I feel indecisive	1	2	3	4
15. I am relaxed	1	2	3	4
16. I feel content	1	2	3	4
17. I am worried	1	2	3	4
18. I feel confused	1	2	3	4
19. I feel steady	1	2	3	4
20. I feel pleasant	1	2	3	4

STAIP-AD Test Form Y
www.mindgarden.com

A.3. The Trait Anxiety Inventory

SELF-EVALUATION QUESTIONNAIRE

STAI Form Y-2

Name_____ Date_____

DIRECTIONS

A number of statements which people have used to describe themselves are given below. Read each statement and then circle the appropriate number to the right of the statement to indicate how you *generally* feel. There are no right or wrong answers. Do not spend too much time on any one statement but give the answer which seems to describe how you generally feel.

	ALMOST NEVER	SOMETIMES	OFTEN	ALMOST ALWAYS
21. I feel pleasant	1	2	3	4
22. I feel nervous and restless	1	2	3	4
23. I feel satisfied with myself	1	2	3	4
24. I wish I could be as happy as others seem to be	1	2	3	4
25. I feel like a failure	1	2	3	4
26. I feel rested	1	2	3	4
27. I am "calm, cool, and collected"	1	2	3	4
28. I feel that difficulties are piling up so that I cannot overcome them	1	2	3	4
29. I worry too much over something that really doesn't matter	1	2	3	4
30. I am happy	1	2	3	4
31. I have disturbing thoughts	1	2	3	4
32. I lack self-confidence	1	2	3	4
33. I feel secure	1	2	3	4
34. I make decisions easily	1	2	3	4
35. I feel inadequate	1	2	3	4
36. I am content	1	2	3	4
37. Some unimportant thought runs through my mind and bothers me	1	2	3	4
38. I take disappointments so keenly that I can't put them out of my mind	1	2	3	4
39. I am a steady person	1	2	3	4
40. I get in a state of tension or turmoil as I think over my recent concerns and interests	1	2	3	4

STAIP-AD Test Form Y
www.mindgarden.com

A.4. The Multidimensional Assessment of Interoceptive Awareness

Below you will find a list of statements. Please indicate how often each statement applies to you generally in daily life.

	Circle one number on each line					
	Never					Always
1. When I am tense I notice where the tension is located in my body.	0	1	2	3	4	5
2. I notice when I am uncomfortable in my body.	0	1	2	3	4	5
3. I notice where in my body I am comfortable.	0	1	2	3	4	5
4. I notice changes in my breathing, such as whether it slows down or speeds up.	0	1	2	3	4	5
5. I ignore physical tension or discomfort until they become more severe.	0	1	2	3	4	5
6. I distract myself from sensations of discomfort.	0	1	2	3	4	5
7. When I feel pain or discomfort, I try to power through it.	0	1	2	3	4	5
8. I try to ignore pain	0	1	2	3	4	5
9. I push feelings of discomfort away by focusing on something	0	1	2	3	4	5
10. When I feel unpleasant body sensations, I occupy myself with something else so I don't have to feel them.	0	1	2	3	4	5
11. When I feel physical pain, I become upset.	0	1	2	3	4	5
12. I start to worry that something is wrong if I feel any discomfort.	0	1	2	3	4	5
13. I can notice an unpleasant body sensation without worrying about it.	0	1	2	3	4	5
14. I can stay calm and not worry when I have feelings of discomfort or pain.	0	1	2	3	4	5
15. When I am in discomfort or pain I can't get it out of my mind	0	1	2	3	4	5
16. I can pay attention to my breath without being distracted by things happening around me.	0	1	2	3	4	5
17. I can maintain awareness of my inner bodily sensations even when there is a lot going on around me.	0	1	2	3	4	5
18. When I am in conversation with someone, I can pay attention to my posture.	0	1	2	3	4	5

How often does each statement apply to you generally in daily life? Circle one number on each line	Never					Always
19. I can return awareness to my body if I am distracted.	0	1	2	3	4	5
20. I can refocus my attention from thinking to sensing my body.	0	1	2	3	4	5
21. I can maintain awareness of my whole body even when a part of me is in pain or discomfort.	0	1	2	3	4	5
22. I am able to consciously focus on my body as a whole.	0	1	2	3	4	5
23. I notice how my body changes when I am angry.	0	1	2	3	4	5
24. When something is wrong in my life I can feel it in my body.	0	1	2	3	4	5
25. I notice that my body feels different after a peaceful experience.	0	1	2	3	4	5
26. I notice that my breathing becomes free and easy when I feel comfortable.	0	1	2	3	4	5
27. I notice how my body changes when I feel happy / joyful.	0	1	2	3	4	5
28. When I feel overwhelmed I can find a calm place inside.	0	1	2	3	4	5
29. When I bring awareness to my body I feel a sense of calm.	0	1	2	3	4	5
30. I can use my breath to reduce tension.	0	1	2	3	4	5
31. When I am caught up in thoughts, I can calm my mind by focusing on my body/breathing.	0	1	2	3	4	5
32. I listen for information from my body about my emotional state.	0	1	2	3	4	5
33. When I am upset, I take time to explore how my body feels.	0	1	2	3	4	5
34. I listen to my body to inform me about what to do.	0	1	2	3	4	5
35. I am at home in my body.	0	1	2	3	4	5
36. I feel my body is a safe place.	0	1	2	3	4	5
37. I trust my body sensations.	0	1	2	3	4	5

A.5. The R code used in RStudio for statistical analysis

```
library(tidyverse)
library(readr)
library(tidyr)
library(dplyr)
library(effectsize)
library(pwr)
library(ggcorrplot)
library(corrplot)
library(ggplot2)
library(Hmisc)
library('papaja')
library("tinylabels")


~> comments left for easier track of work


Thesis_DataLog <- read_csv("~/Thesis_DataLog.csv")
str(Thesis_DataLog)


~> columns grouped for easier typing:
cols<- c(2, 5:15)
maia <- c("Noticing", "Not_Distracting", "Not_Worrying", "Attention_Regulation",
"Emotional_Awareness", "Self_Regulation", "Body_Listenning", "Trusting")
cvs <- c("SHAM_1PPT", "CVS_1PPT")
stai <- c("STAI-S","STAI-T")


~> time for t.tests, yay
t.test(Thesis_DataLog$CVS_1PPT,
       Thesis_DataLog$SHAM_1PPT,
       paired = TRUE)


RESULTS: t = 3.3029, df = 15, p-value = 0.00483
~> which suggests that the effect is positive, significant, and large
```

```
~>post-hoc effect size:
cohens_d(Thesis_DataLog$CVS_1PPT, Thesis_DataLog$SHAM_1PPT, paired = TRUE)
RESULTS: Cohen d = 0.83

~>Paired t.test power calculation for my sample:
pwr.t.test(
  n = 16,
  d = 0.83,
  sig.level = 0.05,
  type = "paired",
  alternative = "two.sided")
 RESULTS: power = 0.8731247

~> corelations for 1PPT:
FPPTdata_cor <- Thesis_DataLog %>%
  select(all_of(cols), CVS_1PPT, SHAM_1PPT)
cor(FPPTdata_cor)

~> cor matrix down to 1 decimal by:
corrr=round(cor(FPPTdata_cor), 1)

~> corelations for 3PPT:
TPPTdata_cor <- Thesis_DataLog_NApredicted_ %>%
  select(all_of(cols), CVS_3PPT, SHAM_3PPT)
cor(TPPTdata_cor)
corrr_3PPT=round(cor(FPPTdata_cor), 1)

~>Visualization of correlation matrix for 1PPT(asssymetrical Correlogram with hierarchy):
ggcorrplot(corrr, hc.order = TRUE, type = "lower",
           title = "First-Person Perspective Taking",
           legend.title = "Pearson \nCorrelation",
```

```
        lab=TRUE, lab_size = 3)

~> Visualization of correlation matrix for 3PPT:
ggcorrplot(corrr_3PPT, hc.order = TRUE, type = "lower",
        title = "Third-Person Perspective Taking",
        legend.title = "Pearson \nCorrelation",
        lab=TRUE, lab_size = 3)

~> now, og dataset has to be converted into a long format by:
 data_long <- Thesis_DataLog %>%
 pivot_longer(cols = 16:17,
            names_to = c("stimulation", "ppt"),
            names_sep = c("\\_"))
str(data_long)

~> dataset clean up:
data_long$ppt <- NULL

~> Means and sd for CVS/SHAM 1ppt responses calculated by:
data_long %>%
 group_by(stimulation) %>%
 get_summary_stats(value, type = "mean_sd")
RESULTS: CVS(M=0.388, SD=0.225)>SHAM(M=0.288, SD=0.255)

~> Distribution check by:
ggqqplot(data_long, "value", facet.by = "stimulation")

~> boxplot:
 boxplot(value ~ stimulation,
        data = data_long)
```

~> so, looks like cvs lead to a higher median but with outliers, and sham seems to have no outliers and higher variability

~> normality test:

```
data_long %>%
   group_by(stimulation) %>%
   shapiro_test(value)
```

RESULTS: CVS (W=0.805, p=0.00322); SHAM (W=0.882, p=0.0411)

~> reject null, ANOVA shan't, Friedman test it is

~>Friedman test:

```
friedman_test(value ~ stimulation |ID)
```

RESULTS: $\chi^2(1) = 8.07$, df=1, p = 0.00451

~> effect size by:

```
data_long %>% friedman_effsize(value ~ stimulation |ID)
```

RESULTS: Kendall's W=0.504, so large magnitude

~> Cleaner boxplot visualisation by:

```
boxplot(
  value ~ stimulation,
  data = data_long,
  xlab = "Stimulation Type",
  ylab = "Proportions",
  main = "First-Person Perspective Taking")
```