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Bodily self-awareness and body-schematic processes

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In this chapter I review some of the original writings on notions of body-awareness and body schema, specifically in the work of the neurologists Hermann Munk and Henry Head. I draw from these early accounts five ideas that I then test out by examining a recent experimental study of subjects with deafferentation, involving the absence of proprioceptive, tactile, and other somatosensory input. Deafferentation allows us to see some of the insightful implications that these ideas present concerning body awareness and its relation to motor control.

Some historical notes on the body schema

The concept of the body schema involves a confused history of over 130 years. The same year that William James (1890) wrote about the feelings of 'warmth and intimacy' associated with our bodily awareness, Hermann Munk published the second edition of his *Über die Functionen der Grosshirnrinde* (1890), where, in terms of brain physiology, he attempts to experimentally discriminate non-conscious processes driven by activity of the spinal cord, from what he calls the noetic kinesis of the cerebrum (p. 183). If one takes away noetic-kenetic processes due to damage of the cerebrum, however, the animal will still be capable, in a machine-like way, of moving and avoiding obstacles without complicated deliberation or great effort. According to Munk, even with intact motor areas of the cerebrum, it is not possible to generate an isolated image of muscle sensations, although it is possible to generate contact (touch), and pressure images. These 'two kinds of sensations combine to provide a distinct image or idea (*Vorstellung*) of the actual positions of the different parts of the body, and of the changes in position of the various parts of the body in passive movement' (1890, 32). Awareness of active movement involved two factors: movement perception (one can think of this as one's visual perception of moving body parts) and conscious 'innervation' sensations (*Innervationsgefühle*) generated by neuronal activation in midbrain and spinal areas as movement is initiated. In the case of haptic exploration, for example, the innervation sensations combine with pressure and muscle sensations to form an image or representation of the movement that reflects what we might call an ecological aspect: all of these sensations integrate to form a complex internal representation of bodily movement combined with the 'form and extension of the objects touched by the moving members of the body' (1890, 33). In this process, specific parts of the motor areas of the cortex correlate with various body parts. 'The fibres that carry the skin, muscle and innervation sensations from the body terminate in the perceiving central elements of each area, and within these areas, corresponding parts of the body have their seat and are represented. Accordingly, the independent areas of motor cortex (*Fühlsphäre*) represent corresponding parts of the body' (1890, 38).

It's not clear that Munk's proposal reduces the body image to just a visual image, but this seems to be the way that Henry Head (1920) interprets Munk. Oldfield and Zangwill (1942) explain.

> Munk's conception of the motor cortex as a repository of images of movement was sharply contested by Head [1920], who maintains that the term 'image' strictly refers only to that which can be voluntarily recalled into consciousness. He points out that if we sit immobile, and imagine our fingers touching some object, the only image in consciousness is a visual one. Head then proceeds to adduce clinical evidence from cases of cortical lesion to the effect that appreciation of posture and of passive movement may be impaired or abolished without any loss of power to visualize the position of the affected part of the body. (1942, 271).[1]

Head recounts an experiment similar to one conducted on the deafferented patient IW (Cole 1995; see below for further details). If you ask IW, who has no proprioception or sense of touch below the neck, to hold out his arm in front of him, and then ask him to close his eyes, he will be able to visualize his hand and its position, and use his other hand to point to it. If you then move his arm to the side and ask him to point to it, he will point to where he remembers that hand to be. As Head puts it, 'he will continue to see a picture of the hand in its old position…. The visual image of the limb remains intact, although the power of appreciating changes in position is abolished (1920, v.2, 605). So what Munk calls an *Erinnerungsbild*, a memory image, is not sufficient to provide a sense of posture or passive movement. Although it is true that some standard based on knowledge of past position is required, the standard cannot be a visual image. Likewise, '"images of movement", by which he appears to mean kinaesthetic imagery, cannot fulfil this function of supplying postural standards' (Oldfield & Zangwill 1942, 271).

Head thus suggests that the image, 'whether it be visual or motor, is not the fundamental standard against which all postural changes are measured' (1920, v.2, 605). He proposes the concept of a schema to solve the problem.

> Every recognizable change enters into consciousness already charged with its relation to something that has gone before, just as on a taximeter the distance is presented to us already transformed into shillings and pence. So the final product of the test for the appreciation of posture or passive movement rises into consciousness as a measured postural change. For this combined standard, against which all subsequent changes of posture are measured before they enter consciousness, we propose the word 'schema'. By means of perpetual alterations in position we are always building up a postural model of ourselves which

[1] Wernicke (1900) also attempts to explain how the body maintains spatial orientation and organizes somatosensory signals despite constant movement, based on a set of 'images' stored in the sensorimotor cortex.

> constantly changes. Every new posture or movement is recorded on this plastic schema, and the activity of the cortex brings every fresh group of sensations evoked by altered posture into relation with it. Immediate postural recognition follows as soon as the relation is complete. 1920, v.2, 605-6).

I agree with Oldfield and Zangwill, that this idea fits nicely into Munk's framework insofar as he described an integration of pressure, tactile, muscle and innervation sensations (generated by non-conscious sub-cortical efferent mechanisms), and not just visual sensation. This combination of proprioceptive and kinaesthetic processes constitutes the 'combined standard' which Head calls the schema.[2] This schema forms part of the motor control mechanism and does its work non-consciously. '. . .the activities on which depend the existence and normal character of the schemata lie for ever outside consciousness; they are physiological processes with no direct psychical equivalent' (1920, v.2, 723). At the same time these processes generate an awareness of posture and movement, which, as Head proposes, 'enters into consciousness'. Clearly, proprioception, kinaesthesia, vision, and other sensory processes contribute to the workings of the body schema. By the time it enters into consciousness, however, all the work is done. The image or conscious representation of posture and movement is a product of, and does not contribute to, the motoric process. For Head, the visual image, which he considers conscious, is insufficient to establish the body schema.

I want to highlight several ideas that result from the analyses by Head and Munk.

- First, Head indicates that, in the case of normal everyday action, the body is not in the center field of consciousness; like proprioception, it tends to remain recessive. In this respect, it generally has a prereflective status, which means that body-awareness is not the result of reflective attention to the body. The degree of body-awareness may vary from prereflective to reflective awareness, however, depending upon circumstances.
- Second, it is not clear, and Head provides no evidence on this score, that this prereflective awareness of bodily movement cannot loop back into and contribute to the ongoing motor control processes, perhaps, in a similar way to visual perception or visual proprioception, as part of an afferent monitoring mechanism.
- Third, Head insists on the temporality of the sensory-motoric process, and this implies that our awareness of bodily posture and movement is always relational. As Oldfield and Zangwill explain, for Head, the appreciation of bodily posture and movement 'must necessarily presuppose some background of comparison and relation. In postural recognition, awareness of an altered position is immediate, yet the postural sensations rise into consciousness "charged with the relation to something that has happened before"' (1942, 273).

[2] Head discusses a second 'sensory' schema in addition to the postural schema. The sensory schema allows for an awareness of location of sensations on the body surface. I won't discuss this schema, but see Oldfield and Zangwill for some of the complex issues involved, including the notion of protopathic projection that allows this sensory schema to function as a primitive defense mechanism. Recently Frederique de Vignemont (2017; 2018) proposed an additional body schema specifically dedicated to a protective function. It is beyond the scope of this paper to discuss how Head's concept of body schema as involving a defensive or protective function relates to this proposal.

- Fourth, since proprioception is involved, the body schema involves not just sub-cortical and spinal processes, but the entire peripheral nervous system. It is not just a process in the cortex (both Head and Oldfield and Zangwill mention the peripheral system, but emphasize cortical processes), or what Berlucchi and Aglioti (2010) have called 'the body in the brain', but is more fully defined by processes that happen throughout the body.
- Finally, what I called the ecological aspect of Munk's analysis is not noted by Head. In contrast, we should note that the body schema is not just a mechanism that tracks bodily posture and movement *simpliciter*, or in a fashion that is isolated from the environment, but is relational in a second way, insofar as it tracks movement in a way that is always relative to what Munk called the 'form and extension of the objects touched by the moving members of the body' (1890, 33). The body schema, we should say, is not just fully embodied, but also embedded in relation to the environment and to the affordances defined by the situation. It involves a dynamical system of processes that are relationally defined over brain-body-environment.[3] Just as cortical lesions can affect posture and movement, as well as one's awareness of posture and movement, so also can changes in muscular tension (e.g., via vibration techniques), or changes in environment (via manipulations such as moving walls, or specific types of natural or architecturally designed spaces).

In the following sections I'll try to flesh out these ideas and make them more precise by looking at some experiments conducted with subjects who have little or no peripheral input, i.e., cases of deafferentation.

Body schema and body awareness in deafferentation

I'll focus on a recent study of subjects who lack proprioception or touch – specifically two cases of deafferentation (Miall et al. 2021). The question raised by this study is to what degree 'mental representations of the body' can be established and maintained without somatosensory input. Recall that Head suggested that a sense of posture and movement could not be established on the basis of conscious sensation alone. If this means that conscious, and specifically visual, sensation alone cannot establish a body schema, studies of deafferentation will be directly relevant. Miall et al. conduct four experiments to explore the 'mental image' of one's hands, both in regard to (1) shape and (2) the location of landmark parts (finger tips, knuckles, etc.), (3) judgments of arm length for reaching, and (4) attentional bias towards peri-personal space (targets close to *versus* far from hand). This study was conducted with humans, in contrast to Munk's studies which primarily studied dogs using very different methodologies; in each case. however, these studies help to discriminate processes involving body awareness *versus* non-conscious body-schematic processes.

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[3] This is reflected in more recent research that describes the incorporation of tools into an extended body schema and makes this operationally equivalent to an expanded peripersonal space (see Holmes, Calvert & Spence 2004; Maravita & Iriki 2004). Head famously points in this direction, however. 'Anything which participates in the conscious movement of our bodies is added to the model of ourselves and becomes part of these schemata; a woman's power of localization may extend to the feather in her hat' (1920, v.2, 606).

The studies by Miall et al. were conducted with IW, who lost proprioception and touch below the neck over 40 years ago when he was 19 years of age (temperature and pain perception, as well as motor nerve function remain intact), and KS (age: 40 years), who has complete congenital absence of somatosensory signals, including proprioception and touch (also temperature, pain, smell and taste; but vision, hearing and vestibular balance are still intact). One undiscussed assumption made by the researchers was that IW may have, not only Munk's *Erinnerungsbilden*, but, in contrast to KS, something like degraded *Erinnerungs-schemata*, an 'influence from his early somatosensory experience' that could have an effect on his spatial attention. Miall et al. accept the distinction originally discerned in Head, and more clearly defined in Paillard (1999) and Gallagher (1986; 2005), between body image and body schema.

> The body image involves perceptions, mental representations, beliefs, and attitudes towards the body. Though encompassing social and cultural factors, it also includes the ability to think about and make conscious decisions on the shape, size, and location of body parts. In contrast, the body schema is defined as a representation of the positions and movements of the body and its parts in space and which is more directly involved in sensory–motor control, including planning of actions which does not reach consciousness…. Body image and body schema are not independent but instead reciprocally influence each other (Gallagher and Cole 1995). (Miall et al. 2021, 2).

In effect, the researchers understand body image to involve consciousness of the body, and body schema to involve non-conscious processes. Gallagher and Cole (1995) argued that IW, without proprioception and touch, lacked processes that make up the body schema, and that he used an enhanced body image, that is, enhanced consciousness of his body, especially in the visual domain, to guide movement. ter Horst et al. (2012) confirmed that IW's visual imagery processes were enhanced compared to controls, while his proprioceptive-body-schematic processes were impaired. Absence of proprioception and touch (and all somatosensory input) in KS is congenital. She has never experienced somatic sensation; movement guidance is exclusively visual. Deafferentation is more complete in KS since she lacks all somatic sensation in her entire body and head. In this respect one might hypothesize the lack of body-schematic processes in KS. Miall et al., however, present evidence that challenges this conclusion, as well as Head's suggestion that a body schema could not be established on the basis of visual perception alone.

In their experimental designs, Miall et al. assumed that judging the size and shape of one's hands, and locating landmarks on one's hands, involves conscious body-image processes; that reach-distance judgment tasks combine information from visual input and body-schematic processes; and, in contrast, that motoric processes requiring a rapid response rely on automatic, body-schematic mechanisms. Consider some complicating factors. With respect to hand perception, it has long been known that even in neurologically normal adults recognition of one's hands is problematic (Penfield & Boldrey 1937; Wolff 1932). Longo and Haggard (2010) suggest that distortions in perceiving one's own hands, may reflect a distorted somatosensory representation. Cody et al. (2008) cite evidence to suggest that differences in sensory resolution across the limb may be due to differences in basic peripheral innervation patterns, or receptive field properties of neurons in ascending central pathways. With respect to judging reach, neurologically normal adults typically overestimate judgment of their reach, but are more accurate in an action context, when the reaching task is unattended, and when it is a matter of prereflective awareness rather than reflective judgment. This suggests that inaccuracy (e.g., overestimation) is caused by body-image based conscious reflection (Heft 1993). This led the researchers to predict that IW would overestimate reach more than controls. It was more difficult to predict KS's performance. On the one hand, she might show greater accuracy if, due to her congenital deafferentation, she developed an entirely visually-based body image; on the other hand, she reports poor depth perception and poor spatial judgments. Finally, studying attentional bias towards objects that appear closer to our hands can tell us something about non-conscious body-schematic processes which integrate visual and proprioceptive signals in a way that defines peri-personal space (Macaluso & Maravita 2010).

> [D]ifferences in reaction times that depend on target-to-hand distance are seen in normal controls even without direct vision of the hand. In fact, the use of tools that extend reach also extends the range of these attentional effects (Maravita et al. 2003), consistent with the idea that body[-schematic processes that may incorporate such tools] are quite dynamic. We hypothesised that the peri-personal modulatory effect might be exaggerated in deafferented participants as long as the hand is visible, because of their high reliance on visual coding of their body position, but may be diminished or absent when the hand is hidden from direct view. (Miall et al. 2021, 3).

The first two experiments involved (1) conscious judgments about hand size and shape (comparing their own remembered image of their hands *versus* presented images), and (2) conscious judgments about the location of landmarks on their hand (where subjects were asked to indicate location of landmarks (e.g., knuckles) of their own unseen hand on a diagram), respectively. These are two quite different tasks, as the experimenters note, 'the visual representation of hand shape may be quite distinct from metrical knowledge (Miall et al. 2021, 13). At least in part that difference may reflect the underlying difference between estimating the size or shape of a body part and locating a specific point within the boundary of the body – a difference that motivated Head to talk of two different body schemas – one for posture and one for sensory location on the body surface. In this case, however, the task involves a conscious judgment. IW, KS, and controls all performed well on these tasks. Although, on the first task, in all subjects there were systematic biases (on average, 5% reduced length/width ratio in controls), IW and KS showed less bias than controls; accordingly, their estimate of the shape of their unseen hands were significantly more accurate than controls. For the second task, control subjects showed an expected underestimation of finger length (reporting lengths of only 36-37% of actual length), but IW and KS showed greater accuracy and underestimated digit lengths by less than the controls (68.8% for IW; 49% for KS). IW was the most accurate in this regard; KS was closer to controls. This difference between IW and KS, however, rules out the idea that the difference between them and controls may be due to an intersensory distortion introduce by 'topographically skewed somatosensory input' (proprioception, for example, is not as precise as vision; see comments on experiment 3 below and Gallagher 2017). The difference between IW and KS may simply be due to the fact that IW uses his hands more extensively for a variety of tasks than does KS, and thereby uses visual control of hands more than her.[4] These experiments thus suggest that IW and KS can access a body image of their unfelt bodies. 'Vision seems to be sufficient for them to make reliable judgements in these circumstances…. Thus, our study of two rare individuals demonstrates that the conscious body image can be developed and maintained even when without somatic sensation' (Miall et al. 2021, 13).

In this respect, what Munk calls an *Erinnerungsbild*, a memory image, may be sufficient to provide a static sense of shape and landmark locations on the hand (what O'Shaughnessy [1995] calls the 'long-term body image'), but, as Head suggests, not sufficient to provide a sense of occurrent posture or movement which, when one is engaged in action typically requires a body schema or, for IW and KS visual perception. In cases of deafferentation, keeping track of one's moving limbs requires vision.

In the third experiment, on estimating one's reach, controls overestimated the target distance they can reach, which is typical. The overestimation was greater for IW than for controls, and in KS the overestimation was comparable to controls. This result is more difficult to explain. As we noted above, normal adults are more accurate reaching in an action context, when the reaching task is unattended, and when body awareness is prereflective rather than a reflective judgment. In this respect, the intermodal integration involved in the motor control processes of actual reaching may compensate for any imprecision in proprioception. This suggests that the overestimation of normal adults in the experimental situation may be due in part to body-image-based conscious reflection. Moreover, if, in the case of controls, reflective judgment draws on a history of motor processes that are prereflectively attuned in everyday reaching (i.e., body-schematic processes absent in IW), it may explain their higher degree of accuracy (compared to IW) in the experimental situation. It is more difficult to explain KS's performance, although Miall et al. suggested that it may be due to the fact that the younger control group used for KS showed a high variability, compared to the older control group for IW which showed a low mean bias. I'll discuss an alternative explanation of this specific result below, however. Notably, both KS and IW 'reported thinking through and attempting to use surrounding landmarks in making these judgements' about reaching (Miall et al. 2021, 16). This suggests that Munk was right about the importance of the ecological aspects in body-awareness – something that may normally remain a matter of prereflective awareness, but is seemingly a matter of reflective judgment for KS and IW, at least in this experimental situation.

The fourth experiment involves attentional bias to peripersonal space. The experiment tested reaction time (RT) for the detection of visual targets located in peripersonal space, ipsilateral to one's visible or non-visible hand, in contrast to contralateral targets or targets in extra-personal space. Responses to close-by objects generally elicit lower RTs, and are

[4] 'KS does not use her hands much and rarely uses the lateral digits (middle, ring, and little). There are clear abnormalities in the musculoskeletal arrangement of her hands, including an inability to fully extend at the wrist, and in their central control, since she cannot independently move the middle, ring, or little fingers on either hand' (Mialle et al. 2021, 13).

thought to depend on non-conscious, multi-modal integration of visual, haptic, and proprioceptive processes; also, it may serve a protective function (see footnote 2 above). The experiment tested for both visible and non-visible hand. For IW there was no significant differences between visible and non-visible hand, and his RTs were similar to his control group. In contrast KS showed significant differences (ipsilateral versus contralateral) in the visual but not non-visual conditions; but her RTs were consistently lower (quicker) than her control group, and much lower than IW's. This is a surprising result, and it leads to the following interpretation offered by the experimenters: 'These data suggest that KS has a visually based body representation or schema, whereas IW has no discernible body-schema-based representation of peri-personal space'.

This conclusion seems not only a direct challenge to Head's suggestion that a body schema could not be established on the basis of the visual image alone, it suggests that in some cases of deafferentation the subject may employ a working body schema. Given the similarity of their conditions with respect to the absence of proprioception and touch, what accounts for this difference with respect to the presence (in KS) and the absence (in IW) of body-schematic processes?

A minimal but super-fast body schema

It seems paradoxical to think that the fact that KS's deafferentation is both genetic and more complete (compared to IW's deafferentation being acquired and selective) would allow KS but not IW to be capable of body-schematic processes. Miall et al. offer what they admit is a speculative account in terms of visual proprioception. I'll summarize their position and then suggest a slightly different alternative explanation.

Miall et al. suggest that KS relies on a strong capacity for visual proprioception, which they define as 'the unconscious visual representation of the body', which is something IW does not have.

> Again, while speculative, it is possible that visual inputs have replaced somatic inputs in KS's central representations at some point in her development, and she may be able to use such alternative pathways (cerebellar and/or cerebral) without need for cognitive attention. In contrast, such a replacement would not have occurred in IW who matured into adulthood with intact somatosensation. Instead, IW appears to have replaced his loss of somatic input with conscious strategic control. (2021, 17).

I'll take issue with this explanation on a number of points, although I think it does point us in the right direction. First, the characterization of visual proprioception (VP) strikes me as inaccurate. Although VP can be work non-consciously, it may also involve a prereflective conscious aspect, part of an ecological self-awareness described by Gibson (2014) and Neisser (1988). Perhaps, more importantly, it involves, not only a very general position sense (e.g., the fact that I see an object in front of me gives me some information about where I am positioned) but can also contribute to postural control and a sense of movement. Miall et al. cite experiments by Lee and Lishman (1975) which involve, like their famous moving room experiment with toddlers, movement of the environment. In this respect, VP involves changes in the optic flow on the retina occurring when either an agent moves through the environment, or the environment moves, as in the looming or receding walls of the moving room. In the experimental design in Miall et al. where KS is sitting stationary at a table, and there is simply a sudden appearance of a cue or an object in peripersonal space (on a computer screen), VP offers very limited and general information, i.e., about her location relative to the object and that she is not engaged in locomotive movement. Second, the suggestion that KS has VP but that IW does not, is not accurate. Indeed, IW, who is able to drive, and finds driving a car easier than walking around (since there are fewer degrees of freedom to worry about and monitor), experiences VP as his car moves through the environment (also see Yousif, Cole & Diedrichsen 2015). More generally, VP may also help him maintain balance and control posture. In this respect, although we can still say that for IW 'everything is through vision' (Cole 2016), we should not say, at least when he is relying on VP, that 'IW's awareness of his body is *entirely* top–down, constructed through comparatively slow information processing traversing (we propose) conscious visual streams' (Miall et al. 2021, 17; emphasis added). Just here, however, Miall et al. point us in the right direction. Outside of those limited instances where he might rely to some degree on VP (see Cole 2021 on the limitations of this kind of visual feedback in IW), it's true that IW controls most of his movement with conscious vision. Experiments have shown that he activates an area of prefrontal cortex more than control subjects, indicating more conscious control of this movement, and of occipito-parietal cortex, possibly using conscious visual imagery when moving without vision of his body (Cole 2016, 73). Here, then, is an alternative speculative proposal: The difference between IW and KS is not necessarily with respect to VP, but to how it, and other visual cues, are processed in the dorsal visual pathway, which has evolved, in part, to inform pre-motor and motor processes for action (Goodale & Milner 1992). This is fast, non-conscious vision for motor control. It may include visual proprioception, but likely includes more than that.

Accordingly, the difference between KS and IW may involve plastic changes relevant to the dorsal visual stream and motor control processes.[5] IW, who was capable of normal movement until he was 19, had to learn to move differently, without proprioception, and primarily by visual control. Although the loss of touch and proprioception in IW was due to peripheral damage, this likely led to some plastic changes in processes that involve intersensory integration, now lacking proprioception and touch, with visual information via the dorsal stream that typically serves motor control/body-schematic functions. For example, anticipatory postural adjustments (APAs) are involuntary muscle adjustments that precede voluntary movement, and facilitate maintenance of posture. Such motoric adjustments are driven by integrated sensory input, including visual input from the dorsal stream. Thus, the formation or adaptation of APAs can be affected by problems with multisensory integration or with degeneration in areas strongly connected to structures in the dorsal visual pathway (Diedrichsen et al. 2005; Horak & Diener 1994). IW's system, up to the age of 19, had included sensory integration of touch and proprioception, which was disrupted by the neuronopathy. For IW, inputs to the premotor cortex would then be

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[5] Although the neuroscience of VP is not well-known, this neural reorganization in visual pathways likely involves the cerebellum, as Jonathan Cole (private correspondence) and Peggy Mason suggest (see https://neurosciencenews.com/touch-visual-self-17788/)

quite different, with the result that processes may not register properly, or the system might just ignore information, including visual information from the dorsal pathway, that is not properly configured. In IW, conscious visual processing thus becomes more important and substitutes for some non-conscious control mechanisms.

In contrast, in KS, one suspects that the dorsal visual pathway delivered, from the very beginning, a fast processing of visual input that did not have to get integrated with somatosensory information, but that could automatically update some aspects of the motor system. From the beginning her visual system could attune her motoric processes in a way that is both more direct and less complex. It seems to me that this is what Miall et al. are pointing to when they claim that 'visual inputs have replaced somatic inputs in KS's central representations at some point in her development, and she may be able to use such alternative pathways (cerebellar and/or cerebral) without need for cognitive attention…. KS has developed a low-fidelity, automated (fast) motor representation (or schema) whereas IW uses a slow, high-fidelity, cognition-dependent representation for movement control'. It is not just VP but any ecologically attuned visual information (including location of objects close to her body) coming through the dorsal pathway that 'fuel[s] KS's automaticity and rapid responses, [although] it is not sufficient to produce representational accuracy [specifically for her body], which may in turn be reduced by her limited motor experience' (Miall et al. 2021, 17).

In this respect, KS's non-conscious body-schematic processes based on vision are less complex than any found in the control group; like a computer that runs only one program, this schema is much faster (compared to controls) in conditions such as testing attentional bias to peripersonal space. This is clearly a minimal and highly specialized body schema that still requires the supplementation of a conscious body image in most action situations.

Conclusion

To conclude, I want to ask how this latest research on issues that pertain to non-conscious processes and more explicit body awareness aligns with the five ideas that derive from the work of Munk and Head.

- First, recall that for Head, in the case of normal everyday action, the body-image is not in the center field of consciousness. In this respect, body self-awareness generally has a prereflective status, and, like proprioception, tends to remain recessive. By contrast, in cases of deafferentation, a more reflective self-awareness (a conscious perceptual body image) plays a significant role in control of movement. Rather than characterizing subjects who are deafferented as disembodied (see, e.g., Sacks 1998) this more explicit body awareness may lead to an enhanced sense of embodiment. This is apparent in the phenomenological reports of IW and KS, albeit with some difference.

> As IW relates, 'rather than being disembodied, I am completely, totally, embodied. If I was not I would not know where I am. I re-associate and

reconnect constantly' (Cole 2016). KS has been asked repeatedly about her sense of the body. She never hesitates and has always maintained that she has one; when she closes her eyes, the world goes away, but she does not. To illustrate this difference, upon awakening and opening their eyes in the morning, IW goes through a process of re-establishing where his body is, whereas KS simply welcomes back the world to her embodied self. (Miall et al. 2021, 17).

- Second, if KS does have a minimal body schema based on processes in the dorsal visual pathway, one can ask whether such processes generate a prereflective awareness of bodily movement, and whether this contributes to ongoing motor control processes. Based strictly on the phenomenological report cited just above, it is likely that KS does have a prereflective awareness of her body, and this accounts for the difference from IW in her sense of embodiment. IW's body awareness appears to be almost exclusively reflective. It remains an open question, however whether this prereflective awareness contributes to KS's ability to control her movements.

- Although experiments 1 and 2 provide evidence that subjects with deafferentation are able to access what Munk calls an *Erinnerungsbild*, a memory image sufficient to provide a long-term body image, this does not allow IW or KS to keep track of their limbs. IW can sometimes use temperature cues to know where his hands are (he sometimes keeps his hands on his lap and can feel them there via temperature sense), but tracking them during action requires vision and effortful attention (Cole 1995). Such visual tracking nonetheless allows for the temporal relationality that Head indicates as essential for control of action. Conscious tracking slows the process, however. IW reports combining this with cognitively effortful anticipatory processes of previsualization and rehearsal (Cole 2016). For KS, tracking her own movement or the location of her limbs still requires vision. If non-conscious vision (via the dorsal pathway) informs her motor system, however, this may make this tracking less effortful and more automatic for her.

- Fourth, the lack of proprioception and peripheral or somatosensory input, selective in IW, and complete in KS, demonstrates the importance of these processes for normally controlled movement. To the extent that motor control in the case of deafferentation is moved more centrally and becomes more 'in the head', it becomes more effortful. The phenomenology of embodiment shifts from what is typically a recessive or attenuated prereflective awareness of the details of movement and action, to a more explicit body awareness, a more intensive awareness of the details of movement, and a more body-oriented consciousness.[6]

- Finally, these experiments suggest that the ecological aspect, first noted by Munk with specific reference to tactile sensations, continues to play an important role even in cases of deafferentation that do not include tactile sensations. The role of

[6] For very different reasons, this kind of shift to an explicit body image can happen due to specific social factors involving race or gender (Fanon 1986; Young 1998).

visual proprioception or other non-conscious ecological cues in IW and KS indicates the relational nature of body awareness. Action continues to be embedded in relation to the environment and to affordances defined by the situation.[7]

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[7]This made IW something of an expert on the built environment. He spent many years as a disability consultant on projects that involved design for accessibility.

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