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Dissociation between dreams and wakefulness:
Insights from body and action representations
of rare individuals with massive somatosensory deafferentation

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touch; body schema; body image; internal model

Highlights:
• Rare so-called deafferented individuals have lost proprioception and touch
• Deafferented individuals have somatosensory and motor deficits
• Their internal body and action representations are thought to be altered
• We found that deafferented individuals can dream of themselves without disability
• This suggests that distinct representations underlie dreamed and physical actions
Abstract

The realism of body and actions in dreams is thought to be induced by simulations based on internal representations used during wakefulness. As somatosensory signals contribute to the updating of body and action representations, these are impaired when somatosensory signals are lacking. Here, we tested the hypothesis that individuals with somatosensory deafferentation have impaired body and actions in their dreams, as in wakefulness. We questioned three individuals with a severe, acquired sensory neuropathy on their dreams. While deafferented participants were impaired in daily life, they could dream of themselves as able-bodied, with some sensations (touch, proprioception) and actions (such as running or jumping) which had not been experienced in physical life since deafferentation. We speculate that simulation in dreams could be based on former, “healthy” body and action representations. Our findings are consistent with the idea that distinct body and action representations may be used during dreams and wakefulness.
1) Introduction

Why do we dream? Proposed dream functions are numerous but some theories consider dreaming as a form of simulation of the world and the self (see for instance the Threat Simulation theory: Revonsuo, 2000; the Social Simulation theory: Revonsuo et al., 2015a). Windt & Noreika (2011) specifically defined dreams as “offline simulations of waking consciousness arising from internal brain activity” (see also Hobson et al., 2014; Revonsuo, 2000). Despite extensive research on dreams, how the body is represented in dreams remains unclear. Berthoz (1997) and Occhionero & Cicogna (2011) suggested that during dreams, one’s body and action representations may correspond to those used during waking physical life (see also Revonsuo, 2000). This is consistent with simulation theories, reviewed by Berthoz (1997) and Jeannerod (2001), which postulate that cognitive motor processes, including imagined, observed as well as dreamt movements, share the same central representations with executed movements (see also Brecht, 2017; Morasso et al., 2015). Berthoz (1997) postulated that dreams create the illusion of reality by using internal models of the world and the body. From a neurophysiological standpoint, cerebral activity was reported to be similar between dream and wakefulness in several studies, including in the context of actions (Dresler et al., 2011; Nir & Tononi, 2010; Noreika et al., 2020; Revonsuo, 2000; Siclari et al., 2017). This may support the idea that body and action representations used for physical movements are also being used for dreamt movements.

Internal models of the body, which are thought to generate motor commands and predict their sensory consequences, have been proposed to be of prime importance for physical movements (Ghez et al., 2000; Head & Holmes, 1911; Wolpert & Kawato, 1998). It is well established that body and action representations can be updated based on sensory signals, and in particular on somatosensory (proprioceptive and tactile) signals (Cardinali et al., 2016; de
Vignemont, 2009; Gallagher, 1986; Gallagher & Cole, 1995; Ghez & Sainburg, 1995; Paillard, 1999; Sarlegna & Sainburg, 2009). Proprioception is the sense of position and movement of body segments, based on signals from muscles, tendons, joints, and skin (Cole, 2016; Gandevia & Burke, 1992; Pearson, 2001). A few rare individuals have been specifically and massively deprived of proprioception and touch due to a sensory neuropathy. These so-called deafferented individuals experience major motor deficits (Cole & Paillard, 1995; Jayasinghe et al., 2021; Miall et al., 2019). For instance, they typically use a wheelchair as they have impairments in posture and gait (Lajoie et al., 1996), fine motor skills (Cuadra et al., 2019), and coordination (Ghez & Sainburg, 1995). Previous work has shown the effects of deafferentation on body and action representations, including the body schema (de Vignemont, 2009; Gallagher, 1986; Gallagher & Cole, 1995; Paillard, 1999), and the internal model of limb dynamics (Ghez & Sainburg, 1995; Ghez et al., 2000). To compensate for the somatosensory loss, partially at least, deafferented individuals are known to rely on vision and intense attention to movement (Blouin et al., 1993; Cole, 1995; Ingram et al., 2000; Miall et al., 2021b).

As body and action representations are severely altered in deafferented individuals’ physical life, one may ask whether the same body and action representations are used during wakefulness and dreams: in other words, are body and action representations realistic in their dreams or not? Dresler (2015) proposed that dreams are based on “recently experienced information”. Considering this and the simulation theories regarding dreams, we hypothesised that deafferented individuals would have an impaired body and impaired actions in their dreams, as in wakefulness.

Several studies have asked whether body representations are similar in dreams and wakefulness for impaired individuals. They showed that a physical impairment is not necessarily present in dreams. For instance, individuals with acquired blindness were found to retain some forms of visual sensations in dreams (Christensen et al., 2019; Kerr & Domhoff,
2004; Meaidi et al., 2014). Voss et al. (2011) reported congenitally deaf-mute and paraplegic individuals who were never deaf, mute or paraplegic in their reported dreams. It was also reported that voluntary leg movements were dreamt of by 14 out of 15 paraplegic individuals, including some with a congenital impairment (Saurat et al., 2011). These studies suggest that body and action representations can differ between dreams and wakefulness.

Brugger (2008) addressed the issue of the dreamt body representation in amputees: these tended to dream about their body as intact, i.e., as non-amputated (see also Bekrater-Bodmann et al., 2015; Alessandria et al., 2011). In line with this, Mulder et al. (2008) found that 68% of amputees who reported dreaming could dream of an intact body, despite a mean time of twelve years since amputation. Specifically, 31% of the “dreamers” dreamt only of their body as intact and 37% of the “dreamers” dreamt of their body as both intact or amputated. From these results, an alternative hypothesis for our study is that deafferented individuals may dream with a non-deafferented body. To test this, we used questionnaires based on the methods of Mulder et al. (2008) and Voss et al. (2011).
2) Experiment 1

2.1 Participants

Participants were three individuals affected by a chronic, stable sensory neuropathy affecting the large sensory fibers and resulting in the loss of touch and proprioception over the majority of their body (typically from the neck down). GL, IW and WL were, to our knowledge, the only individuals with an acquired, massive yet specifically peripheral loss which has been well characterized in previous studies (see Cole & Paillard, 1995 for a more detailed description of GL and IW’s case reports and clinical conditions; see Miall et al., 2018, 2019 for recent accounts of GL, IW and WL).

IW was a 68 year-old male at the time of participation and became deafferented at age 19. GL was a 72 year-old female and became deafferented at age 31. WL was a 52 year-old female, who also became deafferented at age 31. In summary, all three experienced a substantial loss of large, myelinated afferents as adults. They thus lost touch and the proprioceptive sense of position and movement in the limbs and trunk. IW’s deafferentation was from C3 down while it was from the third branch of the trigeminal nerve down for GL and WL (Miall et al., 2018). Their proprioceptive impairments were illustrated in Miall et al. (2018). No deficit in thermoception was reported, consistent with the idea of a specific loss of the large, myelinated sensory fibres. Recently, GL and IW were found to be impaired in cutaneous mechanical pain (Nagi et al., 2019) and deep pressure pain (Case et al., 2021). The tactile and proprioceptive impairments of these deafferented participants are associated with severe motor impairments, despite preserved motor nerves and muscle function (Miall et al., 2018, 2019; for reviews, Cole & Paillard, 1995; Jayasinghe et al., 2021). All participants gave their written consent to participate prior to the study. They all agreed to be recorded during a videoconference while...
answering a questionnaire. The study was performed in accordance with the standards laid out in The Code of Ethics of the World Medical Association (Declaration of Helsinki). Participants did not receive any payment for their participation. The procedure was approved by the CERSTAPS national ethic committee (‘Comité d’Ethique Pour la Recherche en STAPS’ in France; # IRB00012476-2022-22-03-169).

2.2 Procedure

Participants had to orally answer a questionnaire during an individual videoconference. The average duration of the videoconference was 54 minutes. The questionnaire and the experimental sessions were in English for IW and WL and in French for GL. The questionnaire consisted in 20 questions, including three directly inspired by Mulder et al. (2008). These questions, in bold in the Results section, addressed the issue of the participants’ body, sensations and actions in their dreams. The questionnaire was read and participants’ answers were noted and recorded by the experimenters (ISC and FRS). The experimenters explained that the interest of the study was the body in dreams after deafferentation and urged the participants to take their time to answer. No distinction was made between dreams and nightmares. Once the questionnaire was completed, a few words were exchanged in which comments were welcomed.
2.3 Results

Do you dream since your deafferentation? Never; Monthly; Weekly; Nightly

Participants reported dreaming nightly (WL), weekly (IW) and monthly (GL).

To what extent do you remember your dreams? 0; 1; 2; 3; 4; 5; 6; 7; 8; 9; 10

Although deafferented participants reported that they did not remember well their dreams (GL: 2/10; IW: 4/10; WL: 3/10), they could describe some dreams which are detailed below.

Do you dream of yourself with or without deafferentation?

Only without; Mainly without; Both; Mainly with; Only with

GL dreamt of herself only without deafferentation whereas IW and WL remembered both types of dreams (with and without deafferentation). IW reported: “My dreams with disability may be at the time I could do nothing, with very limited mobility. It may be at times when I was walking with restricted balance and mobility, or it may be that I was in my wheelchair as in currently.” IW also mentioned about his dreams: “I remember quite well leaping from rock to rock down at the beach, rock climbing, jumping, and leaping around. I am just enjoying the movement as anybody else would who is a hundred percent fit. I have dreamed that since my disability.”

Although WL mentioned having both types of dreams (with and without deafferentation), she mentioned: “Sometimes I can walk around, but I have my wheelchair in the background. I drag it with me, but I walk. For example, if there is a stair in my dream, and I have to go up the stairs, I have to bring the chair with me, to carry it. But sometimes it is just in the corner or in the background. I do not use it”. We now present a dream report that may be important when we address in the Discussion whether WL may be considered as non-deafferented in her dreams: “Because I can use my body normally in my dreams, I can walk and all that, it is very
nice, I feel more free. When I am awake, I am struggling with this body that does not work, I have a lot of things I cannot do. So, it is very nice to not have that problem in my dreams”.

If you dream of yourself with deafferentation, when did the shift in dream content take place?

- Immediately (few hours) after the deafferentation; Few days later;
- Few weeks later; Few months later; Few years later

IW started to dream of himself as deafferented a few days after his deafferentation, whereas for WL, it was a few months after. In contrast, GL reported only dreaming of herself as non-deafferented, as mentioned before.

If you dream of yourself with deafferentation, what type of change occurred in the perception of your body in your dreams? (several answers possible)

- Change in the visual aspect; Change in tactile sensations;
- Change in temperature sensations; Change in tiredness sensations;
- Change in pain sensations; Change in possibilities of movements;
- Change in perception of position and movement (of body or limbs)

A change occurred in the possibilities of movements for IW whereas WL reported that a wheelchair appeared in her dreams’ background.
Table 1 summarizes the participants’ answers to the question “Is your body present in your dreams?”. We observed that for all three participants, the body was visually present in their dreams. Other sensations were reported such as feeling of positions and movements, touch, pain, temperature and tiredness, but those answers were less consistent. For instance, WL indicated that she could feel pain in her dreams, as illustrated by this dream report: “Maybe once or twice a year, I have a dream, or a nightmare, where a dog bites my hand and then I wake up. I feel pain, it really hurts”.

| Table 1. Body perception in deafferented participants’ dreams. | }
When asked “Can you describe your most frequent body in your dreams with your own words?”, GL answered: “In my dreams, I see what I really was at 30 years old. As if it was before my deafferentation. I always have about this age in my dreams”. WL also reported feeling without impairment in her dreams: “My body is normal. There is no problem.” She also mentioned “I am not old, I am not young. The age is not an issue. In my dreams, I am probably the same age as I am [now]”. In contrast, IW reported: “There may be times when I am seeing myself in my dreams as being fit, normal. And I may be having some as being with a lot of back pain and not being so good. It fluctuates quite a lot. I think in early years it would have been very much oriented around the concept of my disability and coming to terms with it […].”
Table 2 describes the possibilities of movements in dreams. Most of these actions were impossible for the deafferented participants in physical life. Overall, all participants showed they could dream about a large variety of actions, including standing up, walking, running, jumping and coordinating movements without visual feedback or attention.

<table>
<thead>
<tr>
<th>In my dreams, I can:</th>
<th>GL</th>
<th>IW (in non-deafferented dreams)</th>
<th>WL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stand up</td>
<td>✓</td>
<td>✗</td>
<td>✓</td>
</tr>
<tr>
<td>Walk</td>
<td>✓</td>
<td>✗</td>
<td>✓</td>
</tr>
<tr>
<td>Run</td>
<td>✓</td>
<td>✗</td>
<td>✓</td>
</tr>
<tr>
<td>Jump</td>
<td>✓</td>
<td>✗</td>
<td>✓</td>
</tr>
<tr>
<td>Realize well-coordinated movements without seeing them</td>
<td>✓</td>
<td>✗</td>
<td>✓</td>
</tr>
<tr>
<td>Realize well-coordinated movements without paying attention</td>
<td>✓</td>
<td>✗</td>
<td>✓</td>
</tr>
<tr>
<td>Engage in sports</td>
<td>✓</td>
<td>✗</td>
<td>✓</td>
</tr>
<tr>
<td>Other</td>
<td>Drive a car¹, ride a bicycle, dance, box¹, swim</td>
<td>Play snooker¹, soccer, tennis, ride a bicycle</td>
<td>Fly¹, swim, drive a car</td>
</tr>
<tr>
<td>None of the above</td>
<td>✓</td>
<td>✗</td>
<td>✓</td>
</tr>
</tbody>
</table>

**Table 2. Functional possibilities in deafferented participants’ dreams.**

All activities mentioned in the item “Other” could not be physically performed by participants at the time of the experiment. Activities marked with a ¹ were never physically performed.

Concerning the items “Realize well-coordinated movements without seeing them” and “Realize well-coordinated movements without paying attention”, IW reported: “If I am dreaming as me now, today, disabled, I would have the same issues. If I am dreaming about being fit and normal, I think I dream about what it would have been like back at that time. So,
it depends on the dream”. IW also added: “When I am dreaming as if I am a normal person and I am either walking or standing or doing something normally, I have no recollection of having to think about body position and things like that. So I assume I am in my normal body with all my normal faculties working properly. I can’t remember having to think about balance or things like that”. Examples of dreamt activities include, for GL: “I cycled once in a dream. I had already cycled before [deafferentation]. In this dream, I had no difficulties with my movements, I did not have to focus neither. I was really normal”.

Table 3 summarizes the answers to the question “To what extent is your body in your dreams similar to your current physical body?” regarding different items. IW found difficult to answer some questions on sensations, but he reported that when he dreamt about himself as a non-deafferented person, he was “a fit young healthy guy”. He also reported dreaming about himself as a deafferented person as at the time of the experiment. Overall, he gave a score of 7/10 for the similarity of his physical body compared to his seen body in dreams. When asked specifically about “deafferented dreams”, IW scored a 10 to all questions of Table 3, indicating a complete similarity between his dreamt and physical body.

GL and WL both scored 0/10 for the possibilities of movements, indicating that their movements in dreams did not correspond at all to the movements they could physically perform at the time of the experiment. In addition, for sensations of limb position and movement (proprioception), GL answered 0/10 and WL 1/10. These results indicate that GL and WL’s proprioception and movement possibilities in dreams substantially differed from wakefulness.
Table 3. Body and action similarity between deafferented participants’ dreams and wakefulness.

Since GL always dreamt of herself as a 30 year-old adult, healthy and fully able-bodied, the visual aspect of her body completely differed from her current physical body (0/10; see line 1 of Table 3). Table 3 also shows that GL and WL reported heart rate sensations, more specifically increased heart rate during and after a physical effort, in their dreams. For instance, GL had this dream report: “I was walking up stairs and I was tired. [...] I was not even in my wheelchair. I walked up the stairs tranquilly, but it was so high that I was exhausted, I felt my heart rate increasing. I was standing and walking normally”. IW and WL also felt tiredness in their dreams.

Regarding the need for attention toward motor control, which is known for these deafferented participants, GL and WL reported using less attention in dreams compared to current physical life (GL: 0/10; WL: 2/10; 0/10 being less attention, 5/10 usual amount and
10/10 more attention than used in physical life. IW reported using the same amount of attention (5/10) in dreams as in physical life. For instance, he explained: “If I am dreaming as a normal person, standing, sitting, I am not paying any attention to having to be there, and attending to things like sensations such as movement, touch or visual feedback”. This reflects a similarity between IW’s motor control in “non-deafferented dreams” and during his life before deafferentation. IW also reported: “I do know that I have dreamed that I have got to be very mindful about how I am now walking through the forest with my camera gear up a slope which could be slippery for me. And that I have to be mindful about body position and leaning forward in inclination and speed and a whole raft of things.” IW added “If I am dreaming and I am disabled, I would have the same processes going on that I would have as a disabled person”. This reflects a similarity between IW’s motor control in “deafferented dreams” and in his current physical life.

When asked “Is your body in your dreams most frequently similar or different from your current physical body?”, GL and WL reported respectively 0/10 and 1/10 (see Table 4), indicating that they most frequently dreamt with a body which markedly differed from their physical body, while IW reported 7/10, consistent with the fact that he has both types of dreams: “deafferented” and “non-deafferented”.

Table 4. Body similarity in deafferented participants’ dreams and wakefulness.
Table 5 indicates the participants’ answers regarding their perspective in dreams. GL reported always dreaming from a first-person perspective, and WL often from a first-person perspective. IW reported dreaming from both a first or a third person perspective, irrespectively of the type of dream (“deafferented” or “non-deafferented”).

<table>
<thead>
<tr>
<th>Do you dream of you by seeing yourself:</th>
<th>GL</th>
<th>WL</th>
<th>IW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Always from within my own body</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Often from within my own body</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Either from within my own body or from outside my own body</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Often from outside my own body</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Always from outside my own body</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5. Perspective in deafferented participants’ dreams.

Finally, we asked participants: “Today, do you consider that you have accepted your deafferentation?” Overall, they reported having accepted their somatosensory loss (GL: 10/10; IW: 9/10; WL: 9/10).

3) Experiment 2

3.1 Participants

Participants were IW and WL as GL had passed away before the second experiment was launched. IW was 70 years-old at the time of participation and WL was 54. All participants gave their written consent to participate prior to the experiment. Participants did not receive any payment for their participation. The procedure was approved by the CERSTAPS national ethic committee (# IRB00012476-2022-22-03-169), and was performed in accordance with the

3.2 Procedure

Participants were asked to fill in an online questionnaire in English over a two-week period, as in Voss et al. (2011). They were asked to report their dream(s) as soon as possible after awakening. We specifically asked: “Please tell us everything you can remember of what was going through your mind during the night while you were asleep. Report all events, impressions or feelings, as detailed as possible”. Following each dream report, participants had to answer six questions pertaining to their body, actions, sensations and visual perspective in those dreams. No distinction was made between dreams and nightmares.

3.3 Data analysis

Following the work of Voss et al. (2011), we conducted a content analysis of the dream reports by asking two naive independent raters to judge whether the individual in the dream was disabled or not. For each dream report, we specifically asked: “Did the individual dream of himself/herself with disability (answer 1) or without disability (answer 2)?”. A minimum of ~40 words is typically used as a criterion to include dream reports for further analysis (Koppehele-Gossel et al., 2016; Speth et al., 2013; Voss et al., 2011, 2013). However, this criterion has been suggested to potentially lead to a loss of interesting information (Speth et al., 2013) and in the present experiment, applying such a criterion would have led to the loss of 8 dream reports out of 12. We thus chose not to apply any minimum-word criterion. Both raters were neurologists who received no information about the participants or the research project.
In that context, they were contacted through a third party. Before being sent to raters, dream reports were adjusted by removing any remark not belonging to the dreams themselves, as in Voss et al. (2011). Percentage of agreement was calculated by dividing the number of dream reports for which the raters agreed by the total number of dream reports. Cohen’s (1960) kappa was calculated to quantify the inter-rater agreement. Byrt et al.’s (1993) kappa was also calculated to minimize bias and in particular the “prevalence problem” (Chaturvedi & Shweta, 2015; Hallgren, 2012).

3.4 Results

IW reported his body as present in 12 dreams over two weeks. WL reported dreaming twice over the two-week period and reported that her body was present in one dream only. For the dreams in which the body was present and on a scale from 0 (not at all) to 10 (completely), IW’s reports on how well he remembered varied from 2 to 8 (mean ± SD: 5.2/10 ± 2.0). WL reported remembering her only dream with a score of 2/10. Table 6 indicates that IW was mostly non-deafferented in his dreams. For instance, IW reported: “I was normal, disability was never an issue”; “My actions and reactions were normal. I never gave any consideration to planning movement or thinking about or searching for sensations”; “I was normal, no reference to any disability”.

<table>
<thead>
<tr>
<th>In last night’s dream(s) in which your body was present, did you dream of yourself with or without deafferentation?</th>
<th>Only with</th>
<th>Mainly with</th>
<th>Both</th>
<th>Mainly without</th>
<th>Only without</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>IW</strong></td>
<td>*</td>
<td>*</td>
<td></td>
<td>*</td>
<td></td>
<td>Don’t remember (x2)</td>
</tr>
<tr>
<td><strong>WL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Don’t know</td>
</tr>
</tbody>
</table>

*Table 6. Dreams with or without deafferentation.*
Table 7 describes the possibilities of movements in different dreams. Most of these movements were impossible for the deafferented participants in physical life but both could dream about a variety of movements, including walking without help, running and performing coordinated movements without visual feedback or attention.

Table 7. Functional possibilities in deafferented participants’ dreams.

<table>
<thead>
<tr>
<th>In last night's dream(s) in which your body was present, could you perform actions that you typically do not while awake such as: (several answers possible)</th>
<th>IW</th>
<th>WL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walk with help (someone or something)</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Walk without help (someone or something)</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Run</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>Jump</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engage in sports</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perform well-coordinated movements without seeing them (for instance: walk or drive without looking at your legs)</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Perform well-coordinated movements without paying attention (for instance: walk or drive while talking)</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>None of the above</td>
<td>**</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>Restricted walking, but can't remember mind mapping and planning that I used to do. I sat and steered without attending to those functions. No recall of any disability. I was normal. Stand, balance, shuffle without any cognitive effort. I was normal. I wasn't particularly agile or active, but I can't remember thinking about managing mobility and safety.</td>
<td>I only remember a few situations, suddenly I'm in a different setting, and I do not really see how I move from place to place.</td>
</tr>
</tbody>
</table>

IW reported three times being able to see in his dreams at least parts of his body. He also added regarding one of his dreams: “I could see my body, but wasn’t attending to movement and safety”. Table 8 indicates that participants tended to dream from a first-person perspective.

Table 8. Perspective in deafferented participants’ dreams.

<table>
<thead>
<tr>
<th>In last night's dream(s) in which your body was present, did your dream(s) include seeing yourself:</th>
<th>Always from within my own body (e.g., I cannot see my face nor my back)</th>
<th>Mainly from within my own body</th>
<th>Either from within my own body or from outside my own body</th>
<th>Mainly from outside my own body</th>
<th>Always from outside my own body (e.g., as if I was filmed)</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>IW</td>
<td>**</td>
<td>***</td>
<td>**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WL</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Finally, all dream reports (n=11) from Experiment 2 are presented in Table 9, which also displays raters’ judgments and agreement. In 77.3% (17/22) of the judgments, the two raters judged that the dream’s main character was “healthy” (see yellow cells in Table 9). Raters agreed for 8 of the 11 dream reports (73% of agreement), leading to inter-rater agreements of 0.30 (Cohen’s kappa) and 0.45 (Byrt et al.’s kappa), which may be considered as fair and moderate agreement, respectively (Chaturvedi & Shweta, 2015; Hallgren, 2012).

<table>
<thead>
<tr>
<th>Dream reports</th>
<th>RATER 1</th>
<th>RATER 2</th>
<th>AGREED</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) I dreamed that I was a passenger in a vehicle and driving around a residential area. Then I was in a house, not here, but it was my home... I was on the second floor of a bedroom, then I was suddenly in the living room on the first floor. I was going to show it to a friend. (W) could not report whether the dream was with or without deinstallation.</td>
<td>healthy</td>
<td>healthy</td>
<td>yes</td>
</tr>
<tr>
<td>2) Rescuing kitten. (W) reported this dream as only without deinstallation.</td>
<td>disabled</td>
<td>healthy</td>
<td>no</td>
</tr>
<tr>
<td>3) Undertaking simple repairs on poultry hosing. Walking independent but restricted. Decidedly regards my using a screwdriver and hammer was fine, can’t remember it being a problem. (W) reported this dream as both with and without deinstallation.</td>
<td>disabled</td>
<td>healthy</td>
<td>no</td>
</tr>
<tr>
<td>4) Losing in a line with friends, set in my youth. (W) reported this dream as only without deinstallation.</td>
<td>healthy</td>
<td>healthy</td>
<td>yes</td>
</tr>
<tr>
<td>5) I was driving and had friends in the car. But I have no recollection if the car had hand controls. I have no recollection of the actual process of my driving. (W) could not report whether the dream was with or without deinstallation.</td>
<td>healthy</td>
<td>healthy</td>
<td>yes</td>
</tr>
<tr>
<td>6) Dreamt I was a mother during the reign of Queen Victoria. Active and busy living a normal life with absolutely no sign of my having any disability. (W) reported this dream as only without deinstallation.</td>
<td>healthy</td>
<td>healthy</td>
<td>yes</td>
</tr>
<tr>
<td>7) Last night I dreamt I was being interviewed for a job as a therapist. All sitting down and no running around or activity. (W) reported this dream as only without deinstallation.</td>
<td>disabled</td>
<td>healthy</td>
<td>no</td>
</tr>
<tr>
<td>8) Standing in a bus stop having a conversation with someone. Don’t remember walking to it, or getting on the bus. Just standing in a bus queue talking to the person next to me. I shuffled from foot to foot, and even turned around without attending to my balance, movement or the constant activity of ‘standing’ being safe. I was normal... (W) reported this dream as only without deinstallation.</td>
<td>healthy</td>
<td>healthy</td>
<td>yes</td>
</tr>
<tr>
<td>9) Dreamt I was at a country fair enjoying looking at the farm animals on show. (W) could not report whether the dream was with or without deinstallation.</td>
<td>healthy</td>
<td>healthy</td>
<td>yes</td>
</tr>
<tr>
<td>10) I went back in time. Brief walk in the woods from my youth. Although this time was spent sitting and watching, I had my current dog with me. As far as I can remember, not a thought crossed my mind regards managing my disability. (W) reported this dream as only without deinstallation.</td>
<td>healthy</td>
<td>healthy</td>
<td>yes</td>
</tr>
<tr>
<td>11) Last night I dreamt I was in Westminster and sitting with the members of Parliament and watching the Ukrainian Prime Minister deliver his speech. At the end of the speech everyone rose to applaud. I took the decision not to stand because with my disability it would have been difficult to do so in the cramped conditions. I was singy that, although with care I can stand, my disability stopped me from acknowledging the speech appropriately. (W) reported this dream as only with deinstallation.</td>
<td>disabled</td>
<td>disabled</td>
<td>yes</td>
</tr>
</tbody>
</table>

| Total ‘disabled’ judgments | 7 | 10 |
| Total ‘healthy’ judgments | 1 | 1 |

| % ‘disabled’ judgments | 40% | 70% |
| % ‘healthy’ judgments | 60% | 30% |

| Total inter-rater agreement (yes) | 8 |
| % of inter-rater agreement | 90% | 72.7% |

| Cohen’s kappa | 0.30 |
| Byrt et al.’s kappa | 0.45 |

Table 9. Daily dream reports and raters’ answers.
4) Discussion

The aim of the present study was to investigate body and action representations in dreams of individuals with long term massive deafferentation. We conducted two experiments, and both provided consistent results, as all three deafferented participants reported dreaming, at least sometimes, of themselves as non-deafferented. They reported being able to move freely in their dreams, even though this had not been possible in physical life since deafferentation. We now discuss how this might imply that distinct body representations may be used during dreams and wakefulness.

Distinct perceptual and motor possibilities in dreams and wakefulness suggest distinct underlying body and action representations

The deafferented participants’ answers in both experiments (Tables 1-4, 6 and 7) appear to indicate that their body and actions are not necessarily impaired in their dreams. In our second experiment, two naïve raters judged that the dream’s main character was most often not disabled (Table 9). Overall, the “non-deafferented dreams” of all three participants suggest that their body and action representations used in dreams can be disconnected from those used during daily living.

Results were clear for GL, who was always non-deafferented in her dreams, and IW, who had both “deafferented” and “non-deafferented dreams” (in both experiments), but results might seem more ambiguous for WL. Although WL declared dreaming of herself as both deafferented and not deafferented in Experiment 1, analysis of her “deafferented dreams” suggests that WL did not use her current body and action representations during dreams. Indeed, she always dreamt as someone able to move freely (as before her deafferentation), as well as someone able
to feel somatosensation. Her wheelchair’s appearance in the background was the only link to
deafferentation in her “deafferented dreams”, even though she did not sit in it. This is in
accordance with some reports of individuals with tetraplegia and cerebral palsy who needed a
wheelchair during daily living but who could move freely without a wheelchair in their dreams
(Stensman, 1989). Of note, Stensman (1989) reported for one tetraplegic individual: “in her
dreams, when faced with a hindrance, she took her wheelchair on her back”. In line with this,
Brugger (2008) reported that two women with chronic spinal cord injury “noted the regular
presence of their wheelchair in their dreams. Both emphasized, however, the fact that they
would never or only rarely be seated in this chair. They would rather push the empty
wheelchair!”. Overall, WL’s dream reports lead us to suggest that she was non-deafferented in
her dreams. Regardless, the finding that dreams of WL and other deafferented individuals
included walking, running, standing up and practicing sports is consistent with dreams of
individuals with tetraplegia and cerebral palsy (Stensman, 1989), as well as with paraplegia
(Saurat et al., 2011). Overall, the fact that deafferented individuals can dream as able-bodied is
in accordance with findings from those with paraplegia (Brugger, 2008; Saurat et al., 2011;
Voss et al., 2011), severe visual and hearing impairments (Christensen et al., 2019; Kerr &
Domhoff, 2004; Meaidi et al., 2014; Voss et al., 2011), and amputation (Bekrater-Bodmann et
al., 2015; Brugger, 2008; Mulder et al., 2008).

Several theories suggest that dreaming is a simulation of the world (Dresler, 2015; Hobson
et al., 2014; Revonsuo, 2000; Revonsuo et al., 2015a, 2015b; Windt & Noreika, 2011). It has
also been suggested that the body and action representations used in daily living may be used
in dreams (Berthoz, 1997; Occhionero & Cicogna, 2011). Dresler (2015) specifically proposed
that dreams are based on “recently experienced information”. Based on these ideas, we expected
that the body and action representations currently used during wakefulness would shape dream
content. However, the finding that all three deafferented participants reported dreaming as non-
deafferented even though their loss was at least 20 years ago is consistent with the idea that dreams may not only be based on recently experienced information from their own body.

Revonsuo (2000) suggested that the basis of the threat-simulation mechanism in dreams could be “any available memory traces with highest relative saliency”. We speculate that our participants might have retained memory traces of their former, non-deafferented body and action representations. In line with this idea, Giraux et al. (2001) reported, for an amputee who underwent a bilateral hand transplantation, cortical changes which were consistent with the existence of a “previous pre-amputation somatotopic body representation” (see also Wesselink et al., 2022). Overall, despite a lack of correspondence between dreamt and physical movements, our results may be consistent with simulation theories in which dreams could rely on memory traces of former body and action representations. This is in accordance with findings on healthy control individuals showing that “the bodily dream self appears relatively stable and insensitive to changes of the embodied wake self” (Koppehele-Gossel et al., 2016).

Indeed, movements in our participants’ “non-deafferented dreams” could result from action representations acquired and stored before deafferentation. This could explain the inconsistency between dreamt movements (Tables 2 and 7) and physically-possible movements. Overall, in line with the idea that there are several “bodies in the brain” as underlined by Berlucchi & Aglioti (2010), it is possible that there are at least two types of representations: a current one but also a former one, which may be innate or may have been acquired and stabilized at some point during development. We suggest that the non-deafferented body in the participants’ dreams of the present study could rely on this former, stable representation, which would not be adapted to wakefulness but could be used for “offline simulations” in dreams (Windt & Noreika, 2011). The idea of a former representation seems close to Alessandria et al. (2011)’ speculation that amputees could always dream of them with an intact and completely functional body based on a pre-existing functionally intact body schema (see also Mulder et al., 2008).
“Healthy” body and action representations may also be continuously reinforced by frequent observation of able-bodied individuals (Mulder et al., 2008). Overall, we suggest that multiple body and action representations could be used depending on the context, for instance in dreams and wakefulness.

**Perspective and body representations in dreams**

In the present study, we asked participants which perspective they had in dreams (Tables 5 and 8). Results from our two experiments indicate that GL always dreamt from a first-person perspective, while IW and WL mainly dreamt from a first-person perspective. The finding with GL is consistent with the finding of Arnold et al. (2019) that, when a letter (b, d, p or q) was drawn on her body, GL mostly reported perceiving the letter from a first-person perspective (for instance, when an experimenter drew a “b” on her forehead, she perceived a “d”). The present findings combined to those of Arnold et al. (2019) suggest that the deafferented participant GL may predominantly use a self-centered reference system.

Gallagher (1986) proposed the existence of two types of body representations: the body schema and the body image (although different points of views have been published: de Vignemont, 2009; Gallagher, 2005). The body schema has been described by Galati et al. (2010) as an “egocentric reference”. Given that a first-person perspective was predominantly used in dreams by the deafferented participants in our two experiments, one could speculate that the body schema underlies movements in dreams, as proposed by Occhionero & Cicogna (2011). During “non-deafferented dreams”, deafferented participants might use a former, stable body schema instead of their current defective body schema (Blouin et al., 1993; Cardinali et al., 2016). However, this is highly speculative and further work is necessary, as Cole and
colleagues (Cole & Paillard, 1995; Gallagher & Cole, 1995; Miall et al., 2021a) suggested that in the case of deafferented individuals such as GL or IW, their defective body schema may totally or partially be replaced by the body image.

Interindividual differences in dreams

Out of three deafferented individuals, only IW had dreams in which he was either impaired or unimpaired. Similar reports have been obtained by Mulder et al. (2008) who found that about one third of the amputee participants dreamt of their body as both intact or amputated. In the present study, IW appeared to use current action representations in his “deafferented dreams”, and he reported using attention just as in waking life. It is important to highlight that IW has had to continuously pay great attention to all aspects of movement during wakefulness (Ingram et al., 2000; Lajoie et al., 1996; Miall et al., 2021b). For instance, IW reported that if he has a head cold, he can no longer concentrate enough to control movement (Cole, 2016). Perhaps the combination of his conscious attention and the complex wakeful movements IW has been able to do after deafferentation (such as walking) is relevant to his dream world too, as opposed to GL and WL who have not managed to develop wakeful movement as much (they mostly used a wheelchair after deafferentation, see Cole & Paillard, 1995; Gallagher & Cole, 1995; Miall et al., 2018, 2019). Further work would be useful to determine why IW, but not GL and WL, had “deafferented dreams”. We speculate that this might also be linked to IW’s neck proprioception or his relatively young age (19) at the time of deafferentation. GL and WL both became deafferented at age 31, and may have established more stable non-deafferented body and action representations compared to IW who still was a teenager at the time of deafferentation.
Limitations

Given that only three deafferented individuals (Experiment 1) and then two of these (Experiment 2) participated, the present study should be viewed as preliminary and limited in scope. Similar work with more individuals with major sensory deficits, and healthy individuals, should be conducted to strengthen the results. We also acknowledge that results might have been influenced by memory bias as we could only access memories of participants’ dreams, not their dreams themselves, in particular in Experiment 1.

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