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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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Keywords: body representation; action representation; dream; deafferentation; proprioception;
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

26 Abstract

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

39

40 1) Introduction

41

42 Why do we dream? Proposed dream functions are numerous but some theories consider
43 dreaming as a form of simulation of the world and the self (see for instance the Threat
44 Simulation theory: Revonsuo, 2000; the Social Simulation theory: Revonsuo et al., 2015a).
45 Windt & Noreika (2011) specifically defined dreams as “*offline simulations of waking*
46 *consciousness arising from internal brain activity*” (see also Hobson et al., 2014; Revonsuo,
47 2000). Despite extensive research on dreams, how the body is represented in dreams remains
48 unclear. Berthoz (1997) and Occhionero & Cicogna (2011) suggested that during dreams, one’s
49 body and action representations may correspond to those used during waking physical life (see
50 also Revonsuo, 2000). This is consistent with simulation theories, reviewed by Berthoz (1997)
51 and Jeannerod (2001), which postulate that cognitive motor processes, including imagined,
52 observed as well as dreamt movements, share the same central representations with executed
53 movements (see also Brecht, 2017; Morasso et al., 2015). Berthoz (1997) postulated that dreams
54 create the illusion of reality by using internal models of the world and the body. From a
55 neurophysiological standpoint, cerebral activity was reported to be similar between dream and
56 wakefulness in several studies, including in the context of actions (Dresler et al., 2011; Nir &
57 Tononi, 2010; Noreika et al., 2020; Revonsuo, 2000; Siclari et al., 2017). This may support the
58 idea that body and action representations used for physical movements are also being used for
59 dreamt movements.

60 Internal models of the body, which are thought to generate motor commands and predict
61 their sensory consequences, have been proposed to be of prime importance for physical
62 movements (Ghez et al., 2000; Head & Holmes, 1911; Wolpert & Kawato, 1998). It is well
63 established that body and action representations can be updated based on sensory signals, and
64 in particular on somatosensory (proprioceptive and tactile) signals (Cardinali et al., 2016; de

65 Vignemont, 2009; Gallagher, 1986; Gallagher & Cole, 1995; Ghez & Sainburg, 1995; Paillard,
66 1999; Sarlegna & Sainburg, 2009). Proprioception is the sense of position and movement of
67 body segments, based on signals from muscles, tendons, joints, and skin (Cole, 2016; Gandevia
68 & Burke, 1992; Pearson, 2001). A few rare individuals have been specifically and massively
69 deprived of proprioception and touch due to a sensory neuropathy. These so-called deafferented
70 individuals experience major motor deficits (Cole & Paillard, 1995; Jayasinghe et al., 2021;
71 Miall et al., 2019). For instance, they typically use a wheelchair as they have impairments in
72 posture and gait (Lajoie et al., 1996), fine motor skills (Cuadra et al., 2019), and coordination
73 (Ghez & Sainburg, 1995). Previous work has shown the effects of deafferentation on body and
74 action representations, including the body schema (de Vignemont, 2009; Gallagher, 1986;
75 Gallagher & Cole, 1995; Paillard, 1999), and the internal model of limb dynamics (Ghez &
76 Sainburg, 1995; Ghez et al., 2000). To compensate for the somatosensory loss, partially at least,
77 deafferented individuals are known to rely on vision and intense attention to movement (Blouin
78 et al., 1993; Cole, 1995; Ingram et al., 2000; Miall et al., 2021b).

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

86 Several studies have asked whether body representations are similar in dreams and
87 wakefulness for impaired individuals. They showed that a physical impairment is not
88 necessarily present in dreams. For instance, individuals with acquired blindness were found to
89 retain some forms of visual sensations in dreams (Christensen et al., 2019; Kerr & Domhoff,

90 2004; Meaidi et al., 2014). Voss et al. (2011) reported congenitally deaf-mute and paraplegic
91 individuals who were never deaf, mute or paraplegic in their reported dreams. It was also
92 reported that voluntary leg movements were dreamt of by 14 out of 15 paraplegic individuals,
93 including some with a congenital impairment (Saurat et al., 2011). These studies suggest that
94 body and action representations can differ between dreams and wakefulness.

95 Brugger (2008) addressed the issue of the dreamt body representation in amputees: these
96 tended to dream about their body as intact, i.e., as non-amputated (see also Bekrater-Bodmann
97 et al., 2015; Alessandria et al., 2011). In line with this, Mulder et al. (2008) found that 68% of
98 amputees who reported dreaming could dream of an intact body, despite a mean time of twelve
99 years since amputation. Specifically, 31% of the “dreamers” dreamt only of their body as intact
100 and 37% of the “dreamers” dreamt of their body as both intact or amputated. From these results,
101 an alternative hypothesis for our study is that deafferented individuals may dream with a non-
102 deafferented body. To test this, we used questionnaires based on the methods of Mulder et al.
103 (2008) and Voss et al. (2011).

104 2) Experiment 1

105

106 2.1 Participants

107

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

115 IW was a 68 year-old male at the time of participation and became deafferented at age
116 19. GL was a 72 year-old female and became deafferented at age 31. WL was a 52 year-old
117 female, who also became deafferented at age 31. In summary, all three experienced a substantial
118 loss of large, myelinated afferents as adults. They thus lost touch and the proprioceptive sense
119 of position and movement in the limbs and trunk. IW's deafferentation was from C3 down while
120 it was from the third branch of the trigeminal nerve down for GL and WL (Miall et al., 2018).
121 Their proprioceptive impairments were illustrated in Miall et al. (2018). No deficit in
122 thermoception was reported, consistent with the idea of a specific loss of the large, myelinated
123 sensory fibres. Recently, GL and IW were found to be impaired in cutaneous mechanical pain
124 (Nagi et al., 2019) and deep pressure pain (Case et al., 2021). The tactile and proprioceptive
125 impairments of these deafferented participants are associated with severe motor impairments,
126 despite preserved motor nerves and muscle function (Miall et al., 2018, 2019; for reviews, Cole
127 & Paillard, 1995; Jayasinghe et al., 2021). All participants gave their written consent to
128 participate prior to the study. They all agreed to be recorded during a videoconference while

129 answering a questionnaire. The study was performed in accordance with the standards laid out
130 in The Code of Ethics of the World Medical Association (Declaration of Helsinki). Participants
131 did not receive any payment for their participation. The procedure was approved by the
132 *CERSTAPS* national ethic committee ('Comité d'Ethique Pour la Recherche en STAPS' in
133 France; # IRB00012476-2022-22-03-169).

134

135 2.2 Procedure

136

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

148

149

150

151 2.3 Results

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

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

154

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

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

158

159 **Do you dream of yourself with or without deafferentation?**

160 **Only without; Mainly without; Both; Mainly with; Only with**

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

169 Although WL mentioned having both types of dreams (with and without deafferentation),
170 she mentioned: *“Sometimes I can walk around, but I have my wheelchair in the background. I*
171 *drag it with me, but I walk. For example, if there is a stair in my dream, and I have to go up the*
172 *stairs, I have to bring the chair with me, to carry it. But sometimes it is just in the corner or in*
173 *the background. I do not use it”*. We now present a dream report that may be important when
174 we address in the Discussion whether WL may be considered as non-deafferented in her
175 dreams: *“Because I can use my body normally in my dreams, I can walk and all that, it is very*

176 *nice, I feel more free. When I am awake, I am struggling with this body that does not work, I*
177 *have a lot of things I cannot do. So, it is very nice to not have that problem in my dreams”.*

178

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

181 **Immediately (few hours) after the deafferentation; Few days later;**

182 **Few weeks later; Few months later; Few years later**

183

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

187

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

190 **Change in the visual aspect ; Change in tactile sensations;**

191 **Change in temperature sensations ; Change in tiredness sensations;**

192 **Change in pain sensations ; Change in possibilities of movements;**

193 **Change in perception of position and movement (of body or limbs)**

194 A change occurred in the possibilities of movements for IW whereas WL reported that a
195 wheelchair appeared in her dreams’ background.

196

197 Table 1 summarizes the participants' answers to the question "Is your body present in
 198 your dreams?". We observed that for all three participants, the body was visually present in
 199 their dreams. Other sensations were reported such as feeling of positions and movements, touch,
 200 pain, temperature and tiredness, but those answers were less consistent. For instance, WL
 201 indicated that she could feel pain in her dreams, as illustrated by this dream report: "Maybe
 202 once or twice a year, I have a dream, or a nightmare, where a dog bites my hand and then I
 203 wake up. I feel pain, it really hurts".

Is your body present in your dreams?	GL	IW	WL
No			
Yes	*	*	*
Yes, I see it.	*	*	*
Yes, I feel my positions and movements.	*		
Yes, I have tactile sensations.			*
Yes, I feel pain.		*	*
Yes, I feel temperature.		*	
Yes, I feel tiredness.	*	*	

204

205 Table 1. Body perception in deafferented participants' dreams.

206

207 When asked “**Can you describe your most frequent body in your dreams with your own**
208 **words?**”, GL answered: “*In my dreams, I see what I really was at 30 years old. As if it was*
209 *before my deafferentation. I always have about this age in my dreams*”. WL also reported
210 feeling without impairment in her dreams: “*My body is normal. There is no problem.*” She also
211 mentioned “*I am not old, I am not young. The age is not an issue. In my dreams, I am probably*
212 *the same age as I am [now]*”. In contrast, IW reported: “*There may be times when I am seeing*
213 *myself in my dreams as being fit, normal. And I may be having some as being with a lot of back*
214 *pain and not being so good. It fluctuates quite a lot. I think in early years it would have*
215 *been very much oriented around the concept of my disability and coming to terms with it [...].*”

216

217 Table 2 describes the possibilities of movements in dreams. Most of these actions were
 218 impossible for the deafferented participants in physical life. Overall, all participants showed
 219 they could dream about a large variety of actions, including standing up, walking, running,
 220 jumping and coordinating movements without visual feedback or attention.

In my dreams, I can:	GL	IW (in « non- deafferented dreams »)	WL
Stand up	*	*	*
Walk	*	*	*
Run	*	*	*
Jump	*	*	*
Realize well-coordinated movements without seeing them	*	*	*
Realize well-coordinated movements without paying attention	*	*	*
Engage in sports	*	*	
Other	Drive a car ¹ , ride a horse ¹ , ride a bicycle, dance, box ¹ , swim	Play snooker ¹ , soccer, tennis, ride a bicycle	Fly ¹ , swim, drive a car
None of the above			

221
 222 *Table 2. Functional possibilities in deafferented participants' dreams.*

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

225
 226 Concerning the items "Realize well-coordinated movements without seeing them" and
 227 "Realize well-coordinated movements without paying attention", IW reported: "*If I am*
 228 *dreaming as me now, today, disabled, I would have the same issues. If I am dreaming about*
 229 *being fit and normal, I think I dream about what it would have been like back at that time. So,*

230 *it depends on the dream*". IW also added: "*When I am dreaming as if I am a normal person and*
231 *I am either walking or standing or doing something normally, I have no recollection of having*
232 *to think about body position and things like that. So I assume I am in my normal body with all*
233 *my normal faculties working properly. I can't remember having to think about balance or things*
234 *like that*". Examples of dreamt activities include, for GL: "*I cycled once in a dream. I had*
235 *already cycled before [deafferentation]. In this dream, I had no difficulties with my*
236 *movements, I did not have to focus neither. I was really normal*".

237 Table 3 summarizes the answers to the question "**To what extent is your body in your**
238 **dreams similar to your current physical body?**" regarding different items. IW found difficult
239 to answer some questions on sensations, but he reported that when he dreamt about himself as
240 a non-deafferented person, he was "*a fit young healthy guy*". He also reported dreaming about
241 himself as a deafferented person as at the time of the experiment. Overall, he gave a score of
242 7/10 for the similarity of his physical body compared to his seen body in dreams. When asked
243 specifically about "deafferented dreams", IW scored a 10 to all questions of Table 3, indicating
244 a complete similarity between his dreamt and physical body.

245 GL and WL both scored 0/10 for the possibilities of movements, indicating that their
246 movements in dreams did not correspond at all to the movements they could physically perform
247 at the time of the experiment. In addition, for sensations of limb position and movement
248 (proprioception), GL answered 0/10 and WL 1/10. These results indicate that GL and WL's
249 proprioception and movement possibilities in dreams substantially differed from wakefulness.

To what extent is your body in your dreams similar to your current physical body regarding:	0 (not at all)	1	2	3	4	5	6	7	8	9	10 (completely)
Its visual aspect	GL							IW			WL
Temperature sensations											WL
Pain sensations						WL					
Sweating sensations											
Heart rate sensations									GL	WL	
Tactile sensations			WL								
Sensations of limb position and movement	GL	WL									
The possibilities of movements	GL WL							IW			
Tiredness sensations				WL		GL		IW			

250

251 *Table 3. Body and action similarity between deafferented participants' dreams and*

252 *wakefulness.*

253

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

262 Regarding the need for attention toward motor control, which is known for these
 263 deafferented participants, GL and WL reported using less attention in dreams compared to
 264 current physical life (GL: 0/10; WL: 2/10; 0/10 being less attention, 5/10 usual amount and

265 10/10 more attention than used in physical life). IW reported using the same amount of attention
 266 (5/10) in dreams as in physical life. For instance, he explained: “*If I am dreaming as a normal*
 267 *person, standing, sitting, I am not paying any attention to having to be there, and attending to*
 268 *things like sensations such as movement, touch or visual feedback*”. This reflects a similarity
 269 between IW’s motor control in “non-deafferented dreams” and during his life before
 270 deafferentation. IW also reported: “*I do know that I have dreamed that I have got to be very*
 271 *mindful about how I am now walking through the forest with my camera gear up a slope which*
 272 *could be slippery for me. And that I have to be mindful about body position and leaning forward*
 273 *in inclination and speed and a whole raft of things.*” IW added “*If I am dreaming and I am*
 274 *disabled, I would have the same processes going on that I would have as a disabled person*”.
 275 This reflects a similarity between IW’s motor control in “deafferented dreams” and in his
 276 current physical life.

277

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

283

	0 (most frequently different)	1	2	3	4	5	6	7	8	9	10 (most frequently similar)
Is your body in your dreams most frequently similar or different from your current physical body?	GL	WL						IW			

284

285 *Table 4. Body similarity in deafferented participants’ dreams and wakefulness.*

286

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

	Always from within my own body	Often from within my own body	Either from within my own body or from outside my own body	Often from outside my own body	Always from outside my own body
Do you dream of you by seing yourself:	GL	WL	IW		

291

292 *Table 5. Perspective in deafferented participants’ dreams.*

293

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

297

298 3) Experiment 2

299 3.1 Participants

300

301

302 Participants were IW and WL as GL had passed away before the second experiment was
303 launched. IW was 70 years-old at the time of participation and WL was 54. All participants
304 gave their written consent to participate prior to the experiment. Participants did not receive
305 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

306 standards laid out in The Code of Ethics of the World Medical Association (Declaration of
307 Helsinki).

308

309 3.2 Procedure

310

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

318

319 3.3 Data analysis

320

321 Following the work of Voss et al. (2011), we conducted a content analysis of the dream
322 reports by asking two naive independent raters to judge whether the individual in the dream
323 was disabled or not. For each dream report, we specifically asked: “Did the individual dream
324 of himself/herself with disability (answer 1) or without disability (answer 2)?”. A minimum of
325 ~40 words is typically used as a criterion to include dream reports for further analysis
326 (Koppehele-Gossel et al., 2016; Speth et al., 2013; Voss et al., 2011, 2013). However, this
327 criterion has been suggested to potentially lead to a loss of interesting information (Speth et al.,
328 2013) and in the present experiment, applying such a criterion would have led to the loss of 8
329 dream reports out of 12. We thus chose not to apply any minimum-word criterion. Both raters
330 were neurologists who received no information about the participants or the research project.

331 In that context, they were contacted through a third party. Before being sent to raters, dream
 332 reports were adjusted by removing any remark not belonging to the dreams themselves, as in
 333 Voss et al. (2011). Percentage of agreement was calculated by dividing the number of dream
 334 reports for which the raters agreed by the total number of dream reports. Cohen’s (1960) kappa
 335 was calculated to quantify the inter-rater agreement. Byrt et al.’s (1993) kappa was also
 336 calculated to minimize bias and in particular the “prevalence problem” (Chaturvedi & Shweta,
 337 2015; Hallgren, 2012).

338

339 3.4 Results

340

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

350

In last night’s dream(s) in which your body was present, did you dream of yourself with or without deafferentation?	Only with	Mainly with	Both	Mainly without	Only without	Other
IW	*		*		*****	Don’t remember (x2)
WL						Don’t know

351 Table 6. Dreams with or without deafferentation.

352

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

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)	IW	WL
Walk with help (someone or something)		
Walk without help (someone or something)	* * * *	*
Run	*	
Jump		
Engage in sports		
Perform well-coordinated movements without seeing them (for instance: walk or drive without looking at your legs)	* * *	*
Perform well-coordinated movements without paying attention (for instance: walk or drive while talking)	* * *	
None of the above	* *	
Other	<p>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..</p>	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.

357

358 *Table 7. Functional possibilities in deafferented participants' dreams.*

359

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

In last night's dream(s) in which your body was present, did your dream(s) include seeing yourself:	Always from within my own body (e.g., I cannot see my face nor my back)	Mainly from within my own body	Either from within my own body or from outside my own body	Mainly from outside my own body	Always from outside my own body (e.g., as if I was filmed)	Other
IW	* * * * *	* * *	* *			
WL	*					

363

364 *Table 8. Perspective in deafferented participants' dreams.*

365

366 Finally, all dream reports (n=11) from Experiment 2 are presented in Table 9, which
 367 also displays raters' judgments and agreement. In 77.3% (17/22) of the judgments, the two
 368 raters judged that the dream's main character was "healthy" (see yellow cells in Table 9). Raters
 369 agreed for 8 of the 11 dream reports (73% of agreement), leading to inter-rater agreements of
 370 0.30 (Cohen's kappa) and 0.45 (Byrt et al.'s kappa), which may be considered as fair and
 371 moderate agreement, respectively (Chaturvedi & Shweta, 2015; Hallgren, 2012).

Dream reports	RATER 1	RATER 2	AGREED
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 ... 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. <i>(IW could not report whether the dream was with or without deafferentation)</i>	healthy	healthy	yes
2) Rescuing kitten. <i>(IW reported this dream as only without deafferentation)</i>	disabled	healthy	no
3) Undertaking simple repairs on poultry housing. Walking independent but restricted. Dexterity regards my using a screwdriver and hammer was fine, can't remember it being a problem. <i>(IW reported this dream as both with and without deafferentation)</i>	disabled	healthy	no
4) Living in a flat with friends, set in my youth. <i>(IW reported this dream as only without deafferentation)</i>	healthy	healthy	yes
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. <i>(IW could not report whether the dream was with or without deafferentation)</i>	healthy	healthy	yes
6) Dreamt I was a courtier during the reign of Queen Victoria. Active and busy living a 'normal' life with absolutely no sign of my having any disability. <i>(IW reported this dream as only without deafferentation)</i>	healthy	healthy	yes
7) Last night I dreamt I was being interviewed for a job as a fireman. All sitting down and no running around or activity. <i>(IW reported this dream as only without deafferentation)</i>	disabled	healthy	no
8) Standing at 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 'attending' to being safe. I was normal... <i>(IW reported this dream as only without deafferentation)</i>	healthy	healthy	yes
9) I dreamt I was as at a country fair enjoying looking at the farm animals on show. <i>(IW could not report whether the dream was with or without deafferentation)</i>	healthy	healthy	yes
10) I went back in time. Brief walk in the woods from my youth, although most time was spent sitting and watching. But I had my current dog with me. As far as I can remember, not a thought crossed my mind regards managing my disability. <i>(IW reported this dream as only without deafferentation)</i>	healthy	healthy	yes
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 dangerous to do so in the cramped conditions. I was angry that, although with care I can stand, my disability stopped me from acknowledging the speech appropriately. <i>(IW reported this dream as only with deafferentation)</i>	disabled	disabled	yes
Total 'disabled' judgments	4	1	
Total 'healthy' judgments	7	10	
	% 'disabled' judgments		5/22= 22.7%
	% 'healthy' judgments		17/22= 77.3%
	Total inter-rater agreement (yes)		8
	% of inter-rater agreement		8/11= 72.7%
	Cohen's kappa		0.30
	Byrt et al.'s kappa		0.45

372

373 *Table 9. Daily dream reports and raters' answers.*

374

375 4) Discussion

376

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

384

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

387

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

394 Results were clear for GL, who was always non-deafferented in her dreams, and IW, who
395 had both "deafferented" and "non-deafferented dreams" (in both experiments), but results might
396 seem more ambiguous for WL. Although WL declared dreaming of herself as both deafferented
397 and not deafferented in Experiment 1, analysis of her "deafferented dreams" suggests that WL
398 did not use her current body and action representations during dreams. Indeed, she always
399 dreamt as someone able to move freely (as before her deafferentation), as well as someone able

400 to feel somatosensation. Her wheelchair's appearance in the background was the only link to
401 deafferentation in her "deafferented dreams", even though she did not sit in it. This is in
402 accordance with some reports of individuals with tetraplegia and cerebral palsy who needed a
403 wheelchair during daily living but who could move freely without a wheelchair in their dreams
404 (Stensman, 1989). Of note, Stensman (1989) reported for one tetraplegic individual: "*in her*
405 *dreams, when faced with a hindrance, she took her wheelchair on her back*". In line with this,
406 Brugger (2008) reported that two women with chronic spinal cord injury "*noted the regular*
407 *presence of their wheelchair in their dreams. Both emphasized, however, the fact that they*
408 *would never or only rarely be seated in this chair. They would rather push the empty*
409 *wheelchair!*". Overall, WL's dream reports lead us to suggest that she was non-deafferented in
410 her dreams. Regardless, the finding that dreams of WL and other deafferented individuals
411 included walking, running, standing up and practicing sports is consistent with dreams of
412 individuals with tetraplegia and cerebral palsy (Stensman, 1989), as well as with paraplegia
413 (Saurat et al., 2011). Overall, the fact that deafferented individuals can dream as able-bodied is
414 in accordance with findings from those with paraplegia (Brugger, 2008; Saurat et al., 2011;
415 Voss et al., 2011), severe visual and hearing impairments (Christensen et al., 2019; Kerr &
416 Domhoff, 2004; Meaidi et al., 2014; Voss et al., 2011), and amputation (Bekrater-Bodmann et
417 al., 2015; Brugger, 2008; Mulder et al., 2008).

418 Several theories suggest that dreaming is a simulation of the world (Dresler, 2015; Hobson
419 et al., 2014; Revonsuo, 2000; Revonsuo et al., 2015a, 2015b; Windt & Noreika, 2011). It has
420 also been suggested that the body and action representations used in daily living may be used
421 in dreams (Berthoz, 1997; Occhionero & Cicogna, 2011). Dresler (2015) specifically proposed
422 that dreams are based on "*recently experienced information*". Based on these ideas, we expected
423 that the body and action representations currently used during wakefulness would shape dream
424 content. However, the finding that all three deafferented participants reported dreaming as non-

425 deafferented even though their loss was at least 20 years ago is consistent with the idea that
426 dreams may not only be based on recently experienced information from their own body.

427 Revonsuo (2000) suggested that the basis of the threat-simulation mechanism in dreams
428 could be “*any available memory traces with highest relative saliency*”. We speculate that our
429 participants might have retained memory traces of their former, non-deafferented body and
430 action representations. In line with this idea, Giraux et al. (2001) reported, for an amputee who
431 underwent a bilateral hand transplantation, cortical changes which were consistent with the
432 existence of a “*previous pre-amputation somatotopic body representation*” (see also Wesselink
433 et al., 2022). Overall, despite a lack of correspondence between dreamt and physical
434 movements, our results may be consistent with simulation theories in which dreams could rely
435 on memory traces of former body and action representations. This is in accordance with
436 findings on healthy control individuals showing that “*the bodily dream self appears relatively*
437 *stable and insensitive to changes of the embodied wake self*” (Koppehele-Gossel et al., 2016).
438 Indeed, movements in our participants’ “non-deafferented dreams” could result from action
439 representations acquired and stored before deafferentation. This could explain the inconsistency
440 between dreamt movements (Tables 2 and 7) and physically-possible movements. Overall, in
441 line with the idea that there are several “*bodies in the brain*” as underlined by Berlucchi &
442 Aglioti (2010), it is possible that there are at least two types of representations: a current one
443 but also a former one, which may be innate or may have been acquired and stabilized at some
444 point during development. We suggest that the non-deafferented body in the participants’
445 dreams of the present study could rely on this former, stable representation, which would not
446 be adapted to wakefulness but could be used for “*offline simulations*” in dreams (Windt &
447 Noreika, 2011). The idea of a former representation seems close to Alessandria et al. (2011)’
448 speculation that amputees could always dream of them with an intact and completely functional
449 body based on a pre-existing functionally intact body schema (see also Mulder et al., 2008).

450 “Healthy” body and action representations may also be continuously reinforced by frequent
451 observation of able-bodied individuals (Mulder et al., 2008). Overall, we suggest that multiple
452 body and action representations could be used depending on the context, for instance in dreams
453 and wakefulness.

454

455 *Perspective and body representations in dreams*

456

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

465 Gallagher (1986) proposed the existence of two types of body representations: the body
466 schema and the body image (although different points of views have been published: de
467 Vignemont, 2009; Gallagher, 2005). The body schema has been described by Galati et al.
468 (2010) as an “*egocentric reference*”. Given that a first-person perspective was predominantly
469 used in dreams by the deafferented participants in our two experiments, one could speculate
470 that the body schema underlies movements in dreams, as proposed by Occhionero & Cicogna
471 (2011). During “non-deafferented dreams”, deafferented participants might use a former, stable
472 body schema instead of their current defective body schema (Blouin et al., 1993; Cardinali et
473 al., 2016). However, this is highly speculative and further work is necessary, as Cole and

474 colleagues (Cole & Paillard, 1995; Gallagher & Cole, 1995; Miall et al., 2021a) suggested that
475 in the case of deafferented individuals such as GL or IW, their defective body schema may
476 totally or partially be replaced by the body image.

477

478 *Interindividual differences in dreams*

479

480 Out of three deafferented individuals, only IW had dreams in which he was either
481 impaired or unimpaired. Similar reports have been obtained by Mulder et al. (2008) who found
482 that about one third of the amputee participants dreamt of their body as both intact or amputated.
483 In the present study, IW appeared to use current action representations in his “deafferented
484 dreams”, and he reported using attention just as in waking life. It is important to highlight that
485 IW has had to continuously pay great attention to all aspects of movement during wakefulness
486 (Ingram et al., 2000; Lajoie et al., 1996; Miall et al., 2021b). For instance, IW reported that if
487 he has a head cold, he can no longer concentrate enough to control movement (Cole, 2016).
488 Perhaps the combination of his conscious attention and the complex wakeful movements IW
489 has been able to do after deafferentation (such as walking) is relevant to his dream world too,
490 as opposed to GL and WL who have not managed to develop wakeful movement as much (they
491 mostly used a wheelchair after deafferentation, see Cole & Paillard, 1995; Gallagher & Cole,
492 1995; Miall et al., 2018, 2019). Further work would be useful to determine why IW, but not GL
493 and WL, had “deafferented dreams”. We speculate that this might also be linked to IW’s neck
494 proprioception or his relatively young age (19) at the time of deafferentation. GL and WL both
495 became deafferented at age 31, and may have established more stable non-deafferented body
496 and action representations compared to IW who still was a teenager at the time of
497 deafferentation.

498

499 *Limitations*

500

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

507

508

509

510

511

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