Neurología 40 (2025) 790—806

NEUROLOGÍA

www.elsevier.es/neurologia

REVIEW ARTICLE

Taxonomy of paradigms for neuropsychological assessment of body representation based on a critical review

J.F. Mozo[a,b], **J.M. Ruiz-Sánchez de León**[a,*]

[a] *Facultad de Psicología, Universidad Complutense de Madrid, Campus de Somosaguas 28223 - Pozuelo de Alarcón, Madrid, Spain*
[b] *Instituto de Rehabilitación Neurológica (IRN), C/ Concejal Francisco José Jiménez Martín, 124 Local 28047, Madrid, Spain*

Received 28 September 2022; accepted 2 February 2023

KEYWORDS
Body representation;
Body schema;
Structural description of the body;
Body semantics;
Neuropsychological assessment;
Cognitive assessment

Abstract
Introduction: The concept of body representation overlaps with others, such as body schema, body image, body semantics, structural description, body description or body map. A taxonomy is proposed that classifies body schema, body structural description and body semantics. The aim of this narrative review is to analyze the supply of instruments for neuropsychological assessment of body representation and to propose a classification of their paradigms.
Method: A total of 1,109 articles were obtained and reduced to a total of 71 references by inclusion and exclusion criteria.
Results: A total of 66 instrument names were found, of which 22 were related to body schema, 32 to structural description of the body and 12 to body semantics. Forty five instruments about clinical manifestations not commonly related to neurological etiology (e.g., anorexia, bulimia, hypochondria or schizophrenia) were discarded.
Discussion: A synthesis and classification of paradigms and instruments of interest to the clinic is presented. The need for the creation of validated consensus protocols and their implications are discussed.

PALABRAS CLAVE
Representación corporal;
Esquema corporal;
Descripción estructural del

Clasificación de los paradigmas de evaluación neuropsicológica de la representación corporal tras una revisión crítica

Resumen
Introducción: El concepto de *representación corporal* se solapa con otros, como esquema corporal, imagen corporal, semántica corporal, descripción estructural, descripción corporal o mapa corporal. Se propone una taxonomía que clasifica el *esquema corporal*, la

DOI of refers to article: https://doi.org/10.1016/j.nrl.2023.02.011.
* Corresponding author.
E-mail address: jm.ruiz.sdl@psi.ucm.es (J.M. Ruiz-Sánchez de León).

https://doi.org/10.1016/j.nrleng.2025.09.003

cuerpo;
Semántica corporal;
Evaluación neuropsicológica;
Valoración cognitiva

descripción estructural del cuerpo y la *semántica corporal*. El objetivo de esta revisión narrativa es analizar la oferta de instrumentos de evaluación neuropsicológica de la representación corporal y proponer una clasificación de sus paradigmas.
Método: Se obtuvieron 1.109 artículos y se redujeron a un total de 71 referencias por criterios de inclusión y exclusión.
Resultados: Se encontraron un total de 66 nombres de instrumentos, de los cuales 22 se relacionan con el esquema corporal, 32 con la descripción estructural del cuerpo y 12 con la semántica corporal. Se descartaron 45 instrumentos sobre manifestaciones clínicas no relacionadas habitualmente con etiología neurológica (p.ej. anorexia, bulimia, hipocondría o esquizofrenia).
Discusión: Se presenta una síntesis y clasificación de los paradigmas e instrumentos de interés para la clínica. Se discute sobre la necesidad de creación de protocolos validados de consenso y sus implicaciones.

Introduction

Body representation (BR) was first described by Head and Holmes[1] in 1911, and subsequently by Pick[2] in 1922, when he described the body schema (BSch) and difficulties in recognising posture and locating body parts. Today, the concept of BR is controversial and remains under constant review,[3–6] although 3 underlying constructs are recognised[7,8]: an implicit proprioceptive mechanism, the BSch, defined as a dynamic representation of the relative positions of different body parts, derived from multiple sensorimotor afferent signals (proprioceptive, vestibular, somaesthetic, visual, efference copy signals, etc); and 2 explicit, conceptual mechanisms: *a)* body structural description (BSD), a visual and somaesthetic mechanism defined as a continuous map of different locations derived from visual afferent signals that define the boundaries of body parts and their relationships with nearby objects[9]; and *b)* body semantics (BS), also known among neurologists as body image (a term also referring to the psychiatric concepts of self-conception and self-image), a lexical-semantic mechanism that includes the names of body parts, their functions, and their relationships with objects (Table 1).[10,11]

There is relative consensus regarding the anatomical correlates of these mechanisms: the left dorsolateral prefrontal cortex for BSch[7]; the insula and superior temporal areas, as well as the extrastriate area at the right parieto-occipital junction for BSD[12–14]; and left recruitment for BS, with greater involvement of the left hemisphere.[13,15] Developmental studies of healthy populations have reported that BR develops from the age of 10 years, and declines somewhat after 60 years of age,[16,17] with a prevalence of 51%-81% among the population with stroke.[7,18]

Table 1 Taxonomy of body representation.

Mechanism	Implicit	Explicit	
Representation	Perceptual	Conceptual	
	Proprioceptive	Visual	Semantic
Construct	BSch	BSD	BS

BS: body semantics; BSch: body schema; BSD: body structural description.

Over the years, numerous articles have reported symptoms of impaired BR and body awareness,[3,6] including allochiria, Gerstmann syndrome, heterotopagnosia, autotopagnosia, body integrity dysmorphia, and phantom limbs, among others, and their relationship with signs including apraxia,[19–21] aphasia,[10,22] and neglect.[15,23,24] Effectively, BR is closely related to other cognitive processes, such as working memory,[18] language,[18] and motor control[19]; however, no comprehensive description of these relationships has yet been published.[18]

In general, BR has always been evaluated through verbal or non-verbal commands, with patients instructed to point to different body parts on their own or somebody else's body,[22,25] to construct a body using different body parts,[26] to make a drawing,[27] or to indicate the laterality of a body.[28–30] Though the majority of instruments have been used in experimental tasks with individual patients,[8,25] recent years have seen increased replication and larger patient samples.[7,13,15,18,19,31,32]

In Spain, the only instrument available for assessing BR is the Barcelona Test 2, whose modules 1 and 4 include 7 brief subtests in which patients are required to name, understand, or point to body parts, and to recognise their laterality.[33] The remaining tests were mostly developed in other countries including Italy (eg, the Frontal Body Evocation task), Poland (eg, the Designating Body Parts task), and the United States (eg, the Matching Body Parts to Objects task),[7,18,22,26] with no Spanish-language validation studies having been published. The objective of this review is to analyse the existing neuropsychological assessment instruments addressing BR in adults and children, and to propose a series of recommendations in this regard; we conducted a narrative systemic review in accordance with the PRISMA criteria (see Supplementary Material 1).[34] To our knowledge, no similar review has previously been published.

Material and methods

Search strategy

Given the conceptual breadth and diversity of terms observed after searching for the term body representation (BSch, BSD, BS, and body image),[7,8] we used the descriptors for each term in each database (thesaurus, MeSH, descriptors, or indices) and conducted a preliminary review with each term to assess the volume and precision of results on an individual basis.

The terms ''body schema,'' ''body structural description,'' and ''body semantics'' are not indexed in all databases, whereas ''body image'' is. ''Body image'' is a search term than often belongs to both the semantic fields of neurology and psychiatry; therefore, we decided to use it as a main search term to avoid excluding true negative articles between fields. Furthermore, we observed that the term ''body image'' was also included in studies related to BSch, BSD, and BS; therefore, using this search term ensured that no cognitive study addressing BR was excluded.

The literature search was conducted between January and February 2022. The keywords selected for the literature search were ''body image'' and ''neuropsychological assessment.''

The search was performed on the following databases: PubMed (MeSH), PsycINFO (Thesaurus), PSICODOC (Indices), Psyke (Descriptors), Web of Science (Keywords), Scopus (Keywords), and Teseo. The search strategy was as follows: (''body image'') AND (''neurops*''). Results were filtered for articles written in English or Spanish. We accessed each database through the affiliated distributors via the Universidad Complutense de Madrid and the Spanish Foundation for Science and Technology (FECYT, for its Spanish initials). We also searched the grey literature; no filter was applied to year of publication, with all articles published up to 2022 included.

Article selection strategy

The inclusion criteria used were *a)* articles addressing the assessment of BSch, BSD, or BS; and *b)* articles including at least one BR assessment instrument. The exclusion criteria were *a)* articles studying psychiatric or personality disorders without referring to BR assessment; and *b)* articles studying BR assessment but using instruments related to beliefs, attitudes, or psychoaffective factors, with no item referring to or potentially related to cognitive or neuropsychological analysis.

The literature search, article selection, and data extraction were conducted by the lead author (JFM), while articles were definitively included or excluded by the second author (JMRS), acting as an external reviewer. Furthermore, the Connected Papers software (https://www.connectedpapers.com/) was used to confirm the findings, using the keyword ''body semantics'' and assuming the term to be equivalent to the combination of the terms ''body image'' and ''body schema.''

Results

A total of 1109 articles were identified, of which a total of 71 remained after application of selection criteria (Fig. 1). We identified a total of 14 assessment paradigms, with 66 original names of instruments of neurological interest (Table 2). Twenty-two were related to BSch, and were administered to a total of 2384 subjects; 32 were related to BSD, and were administered to 1781 subjects; and 12 were related to BS, and were administered to 915 subjects (Table 3). As there were occasions on which a single subject was evaluated with different tasks belonging to a single construct, Table 4 presents all the paradigms and the total number of subjects examined with each. The most prevalent study population was healthy adults, and the paradigm with the most frequent and longest history of use was left-right judgement, evaluating BSch. We also excluded 45 instruments related to nuclear aspects of psychiatry, personality, belief (self-conception or self-image), attitudes, and other psychoaffective factors; these are listed in Supplementary Material 2. Supplementary Material 3 lists the study populations identified in the search, classified by medical specialty.

Evaluation of body schema

The most widely used paradigm was left-right judgement (1658 subjects), in which participants are asked to identify a body part as belonging to the left or right side of the body,[7,17,18,30,31,35–39] or whether an item is located to the left or to the right side of a body.[40–46] Performing these tasks requires the existence of a standard, canonical body schema that is accurately represented in the brain, in order to subsequently perform a spatial transformation enabling matching to the visual analysis of the stimulus presented.[30,46,47] Therefore, the subject performs a mental rotation of their own body from an egocentric perspective,[45] using internal spatial and kinematic coding of their own body.[21,48]

The gold standard in this paradigm is the Hand Laterality Task,[30,49] which has been replicated or adapted in multiple studies with different names,[7,18,20,23,31,32,37,50] numbers of stimuli,[7,18,20,21,31,32] stimulus orientation and manipulation,[23,32,47] and types of response.[7,18,23,31,32] Technological advances have enabled electronic administration of this paradigm using mobile apps (eg, Recognise App by the Neuro-Orthopedic Institute; Adelaide, South Australia; Fig. 2).[19,51,52] The use of apps enables better control of stimulus types and increases the precision of data recording.[19,51,52]

Another paradigm is same/different matching,[21,31,53,54] which also demands spatial transformation as a function of a bodily stimulus. In these tasks, subjects are required to indicate whether 2 visual stimuli show the same or different body positions (Fig. 3). Stimuli may be presented sequentially or simultaneously.[21,31,53]

Finally, in imitation paradigms, subjects are asked to watch and repeat an action, and to imagine and accurately perform a movement; this enables comparison of the time taken and the accuracy in completing each task (eg, rapidly pinching the fingers 5 times).[7,18,31,55] Imitation also involves access to an internal configuration of the body position of the person performing the action, particularly for meaning-

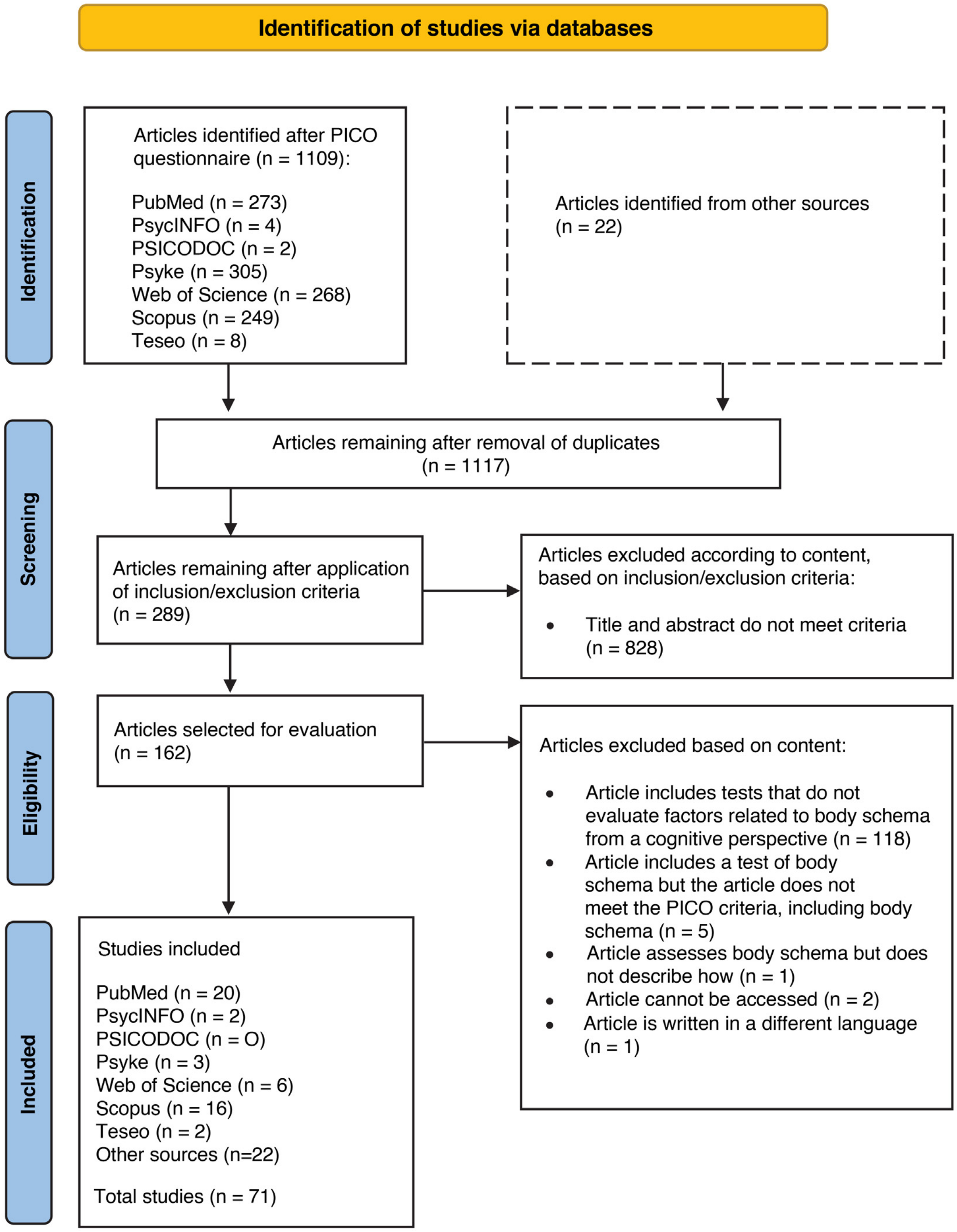

Figure 1 PRISMA 2020 flow diagram[34] depicting the literature review on body representation assessment instruments. As this was an exploratory study, we did not establish inclusion or exclusion criteria for type of study; therefore, the PRISMA 2020 criteria were only partially applied (e.g., we did not exclusively include randomised controlled trials).

less gestures (e.g., imitating the position of a fist beneath the chin as demonstrated by the examiner).[7,21,56–58]

Evaluation of body structural description

The body part localisation paradigm is based on the test developed by Semenza and Goodglass[22] to assess autotopagnosia (inability or difficulty locating parts of one's own body). In general terms, it consists in asking the subject to indicate the locations of different parts of their own body, somebody else's body, or in an image or photograph, on a mannequin, or on a sheet with depictions of multiple body parts.[7,18,22,25,31] It should be noted that this paradigm should be used first, or even exclusively, in a non-verbal form[18,59] in order to avoid influencing the use of language and BS, and that the double dissociation with heterotopagnosia in the absence of autotopagnosia was only studied years later.[60–62]

Body part localisation tests have been adapted to different population profiles, with differences in the type

Table 2 Taxonomy of instruments and paradigms for the neuropsychological evaluation of body representation.

Paradigm	Country	Instruments	Population (age)	Author
Body schema				
Left-right judgement	USA	*Left-Right Discrimination Test*	66 HC (4-8)	Benton,[28] 1959
	USA		76 TBI, 32 HC	Semmes et al.,[66] 1963
	USA		8 HC (university students)	Cooper et al.,[46] 1975
	Spain	*Piaget-Head*	48 motor deficits (M: 10)	Sangorrín García,[81] 1977
	USA	*Left-Right Judgements of an Outstretched Arm of a Body in Observer's Frontoparallel Plane*	68 HC (university students)	Parsons,[30] 1987
	USA	*Foot Laterality Task* (FLT)	22 HC (university students)	Parsons,[49] 1987
	USA		89 HC (university students)	Parsons,[48] 1994
	USA	*Hand Laterality Task*	2 epilepsy (41-42); 8 HC (M: 37)	Parsons et al.,[47] 1998
	USA	*Identification of Hands in Different Positions Task*	13 stroke (M: 59.07)	Coslett[23] (1998)
	USA		1 dementia (62); 1 HC (62)	Buxbaum et al.,[21] 2000
	USA	*Mental Own-Body Transformation Task* (OBT)	24 HC (19-31)	Zacks et al.,[45] 2002
	USA	*Right-Left Hand Discrimination Task*	1 dementia (62)	Coslett et al.,[11] 2002
	USA		55 stroke (M: 58); 18 HC (M: 47)	Schwoebel et al.,[20] 2004
	USA		70 stroke (M: 55); 18 HC	Schwoebel and Coslett,[7] 2005
	Switzerland		11 HC (M: 26.8)	Blanke et al.,[41] 2005
	Switzerland/UK	*Mirror Task* (MIR)	24 HC (M: 26.85)	Arzy et al.,[40] 2006
	UK/Switzerland		48 HC (M: 27.3)	Easton et al.,[43] 2007
	Switzerland		59 MS (59); 5 HC (M: 60.2)	Overney et al.,[44] 2009
	The Netherlands		18 amputees (M: 62.8); 18 HC (M: 57.0)	Curtze et al.,[36] 2010
	USA		82 pain (M: 48.65); 38 HC (M: 45.2)	Coslett et al.,[38] 2010
	Brazil	*Oral Hand Laterality Task* and *Motor Hand Laterality Task*	61 CP (M: 8); 30 HC (M: 5)	Fontes et al.,[31] 2014
	Australia/Italy/UK		32 stroke (M: 64.9); 36 HC (61.1)	Amesz et al.,[52] 2016
	Israel		1 TBI (22), 14 HC	Krasovsky et al.,[50] 2017
	Poland		50 ABI (M: 67.71); 50 HC (M: 68.71)	Razmus,[18] 2017
	Russia	*Left-Right Task*	23 tumour (M: 36.7)	Nikishina et al.,[35] 2018
	Canada		61 pain (M: 55.82)	Pelletier et al.,[51] 2018
	Italy	*Visuospatial Imagery Task*	30 CP (M: 11.65); 30 HC (M: 11.47)	Butti et al.,[42] 2019

Table 2 (*Continued*)

Paradigm	Country	Instruments	Population (age)	Author
	Ireland/Italy/UK		30 stroke (M: 50)	Lane et al.,[19] 2021
	Italy		65 HC (7-8); 37 HC (9-10); 50 HC (18-40); 50 HC (41-60); 37 HC (> 60)	Raimo et al.,[17] 2021
Same/different matching	USA	*Same-Different Visual Matching Task for Body Position Memory*	65 HC (university students)	Reed and Farah,[54] 1995
	USA	*Gesture Matching*	1 dementia (62); 1 HC (62)	Buxbaum et al.,[21] 2000
	USA		1 TBI (48)	Buxbaum and Coslett,[9] 2001
	Brazil	*Hand Matching Task*	30 HC (M: 5)	Fontes et al.,[31] 2014
	Italy	*Same-Different Visual Matching Task for Body Postures*	3 stroke (M: 67.66); 18 HC (M: 64.3)	Olgiati et al.,[53] 2017
	Italy		90 HC (7-10); 37 HC (18-35)	Raimo et al.,[39] 2019
	Italy		26 stroke (M: 56.07); 39 HC (M: 57.67)	Boccia et al.,[13] 2020
	Italy		33 CP (M: 7.69); 103 HC (M: 8.04)	Di Vita et al.,[32] 2020
	Italy		64 stroke (M: 58.39); 41 HC (M: 58.39)	Raimo et al.,[15] 2022
Observation and imitation (meaningless gestures)	USA	*Hand Imagery* and/or *Action Task*	4 ABI (M: 47)	Sirigu et al.,[55] 1996
	Germany	*Imitation of Meaningless Gestures*	205 stroke (M: 58.20); 90 HC (M: 54.75)	Goldenberg,[56–58] 1995, 1996, 2001
	USA	*Imitation of Meaningless Gesture Analogs*	1 dementia (62); 1 HC (62)	Buxbaum et al.,[21] 2000
	USA		70 stroke (M: 55) 18 HC	Schwoebel and Coslett,[7] 2005
	Brazil		61 CP (M: 8); 30 HC (M: 5)	Fontes et al.,[31] 2014
	Poland	*Hand Action Task*	50 stroke (M: 67.71); 50 HC (M: 68.71)	Razmus,[18] 2017
	Russia	*Head's Test* and *The Test of Transfer of Position from one Hand to Another*	23 tumour (M: 36.7)	Nikishina et al.,[35] 2018
Body structural description				
Body part localisation	UK	*In-Between Task*, *Point Finger Test*, *Matchbox Test*, and *Finger Block Test*	12 Gerstmann syndrome (M: 54); 20 ABI (54.45)	Kinsbourne and Warrington,[82] 1962
	USA	*Pointing to Those Parts of His Own Body Associated With a Number*	76 TBI (adults)	Semmes et al.,[66] 1963
	Spain		48 motor deficits (M: 10)	Sangorrín García,[81] 1977
	Italy/USA	*Semenza and Goodglass Test*	32 stroke (M: 51.46)	Semenza and Goodglass,[22] 1985
	New Zealand	*Pointing to Parts of the Body on Himself by Imitation*	1 tumour (59)	Ogden,[25] 1985
	USA	*Localization of Objects on the Body*	1 dementia (62); 10 HC (adults)	Sirigu et al.,[8] 1991

Table 2 (*Continued*)

Paradigm	Country	Instruments	Population (age)	Author
	Italy		1 stroke (42)	Guariglia and Antonucci,[69] 1992
	Japan		1 stroke (66)	Suzuki et al.,[10] 1997
	USA	*Finger Grouping on Finger Identification Task*	13 stroke (M: 59.07)	Coslett et al.,[23] 1998
	Italy	*Body Part Localization Task*	1 stroke (67)	Denes et al.,[72] 2000
	USA	*Matching Body Parts: Effect of Impoverishment/Variability in Visual Features Task*	1 TBI (48)	Buxbaum and Coslett,[9] 2001
	USA	*Localization of Named Body Parts Task* and *Pointing to Pictured or Named Body Part on Oneself Task*	1 dementia (62)	Coslett et al.,[11] 2002
	Italy		1 stroke (78)	Guariglia et al.,[65] 2002
	France	*Body Part Pointing Tasks*	2 dementia (68-73)	Felician et al.,[60] 2003
	Italy		1 stroke (78)	Marangolo et al.,[70] 2003
	USA		55 stroke (M: 58); 18 HC (M: 47)	Schwoebel et al.,[20] 2004
	USA		70 stroke (M: 55); 18 HC (adults)	Schwoebel and Coslett,[7] 2005
	The Netherlands	*Finger Tactile Stimulus* and *Pointing Toward the Real Finger Touched Task*	7 stroke (61-81); 1 epilepsy (31)	Anema et al.,[83] 2008
	France	*Structural Knowledge of Body* and *Localization of Objects on the Body*	1 stroke (72)	Auclair et al.,[63] 2009
	France	*Body Part Pointing Tasks*	3 stroke (M: 59.66)	Cleret de Langavant et al.,[62] 2009
	Italy/UK	*Intermanual In-Between Task*	44 HC (M: 26)	Rusconi et al.,[84,85] 2009, 2014
	Brazil	*Image Marking Procedure*	16 pain (M: 23.9); 20 HC (23.6)	Thurm et al.,[86] 2013
	Brazil	*Verbal Body Part Localization Task*, *Visual Body Part Localization Task*, and *Pointing to Named Body Parts Task*	61 CP (M: 8); 30 HC (M: 5)	Fontes et al.,[31] 2014

Table 2 *(Continued)*

Paradigm	Country	Instruments	Population (age)	Author
	Italy		1 stroke (62)	Di Vita et al.,[64] 2015
	Poland		50 stroke (M: 67.71); 50 HC (M: 68.71)	Razmus,[18] 2017
	Israel	*Body Part Pointing Tasks*	1 TBI (22); 14 HC (adults)	Krasovsky et al.,[50] 2017
	Russia		23 tumour (M: 36.7)	Nikishina et al.,[35] 2018
	Germany		37 stroke (M: 60.13); 19 HC (59.7)	Dafsari et al.,[59] 2019
	Switzerland		1 stroke (60)	Bassolino et al.,[61] 2019
	Switzerland/Italy		32 stroke (59.25)	Ronchi et al.,[87] 2020
Matching body parts by location	USA	*Contiguity Task*	1 dementia (62)	Coslett et al.,[11] 2002
	USA	*Matching Body Parts by Location Task*	70 stroke (M: 55); 18 HC	Schwoebel and Coslett,[7] 2005
	France		1 stroke (72)	Auclair et al.,[63] 2009
	Brazil		61 CP (M: 8); 30 HC (M: 5)	Fontes et al.,[31] 2014
Paradigm	Country	Instruments	Population (age)	Author
	Poland		50 ABI (M: 67.71); 50 HC (M: 68.71)	Razmus,[18] 2017
Visual construction of the body	Spain		48 motor deficits (M: 10)	Sangorrín García,[81] 1977
	Spain	*Body Representation Test* and *Drawing Task*	100 HC (7-11)	Daurat-Hmeljiak et al.[26] 1978; Spanish adaptation: Jiménez,[27] 1978
	Italy	*Frontal Body-Evocation Task* (FBE)	1 stroke (42)	Guariglia and Antonucci,[69] 1992
	Japan	*Mental Imagery Drawing* and *Drawing Task*	1 stroke (66)	Suzuki et al.,[10] 1997
	Italy		1 stroke (78)	Guariglia et al.,[65] 2002

Table 2 (*Continued*)

	Italy		1 stroke (78)	Marangolo et al.,[70] 2003
	Italy		1 stroke (70)	Canzano et al.,[68] 2011
	Italy		32 ABI (M: 59.56); 18 amputees; 15 HC (M: 55)	Palermo et al.,[67] 2014
	Italy	*Human Figure Drawing Task*	1 stroke (62)	Di Vita et al.,[64] 2015
	Italy		23 stroke (M: 64.69); 16 HC (M: 66.44)	Di Vita et al.,[24] 2017
	Italy		90 HC (7-10); 37 HC (18-35)	Raimo et al.,[39] 2019
	Italy		23 stroke (M: 60.57); 9 HC (M: 60.33)	Di Vita et al.[12] 2019
	Italy		33 CP (M: 7.69); 103 HC (M: 8.04)	Di Vita et al.[32] 2020
	Italy		26 stroke (M: 56.07); 39 HC (M: 57.67)	Boccia et al.,[13] 2020
	Italy		65 HC (7-8); 37 HC (9-10); 50 HC (18-40); 50 HC (41-60); 37 HC (> 60)	Raimo et al.,[17] 2021
	Italy		64 stroke (M: 58.39); 41 HC (M: 58.39)	Raimo et al.,[15] 2022
Explicit body knowledge	France		3 stroke (M: 59.66)	Cleret de Langavant et al.,[62] 2009
	Italy		3 stroke (M: 67.66); 18 HC (M: 64.3)	Olgiati et al.,[53] 2017
	Italy	*Visual Body Recognition Task*	30 CP (M: 11.65); 30 HC (M: 11.47)	Butti et al.,[42] 2019
	France		103 HC (M: 66.6)	Baumard et al.,[16] 2020
Implicit body knowledge	Italy	*Sideness test*	95 HC (university students)	Ottoboni et al.,[71] 2005
	Ireland/Italy/UK		30 stroke (M: 50)	Lane et al.,[19] 2021
Body semantics				
Body part naming	New Zealand	*Watching While the Examiner Points to Body Parts on Another Person on Verbal Command*	1 tumour (59)	Ogden,[25] 1985
	USA	*Naming Body Parts Task*	1 dementia (62); 10 HC (adults)	Sirigu et al.,[8] 1991
	Italy		1 stroke (67)	Denes et al.,[72] 2000
	USA		1 dementia (50)	Coslett et al.,[11] 2002
	Italy		1 stroke (78)	Guariglia et al.,[65] 2002
	The Netherlands	*Finger Naming*	2 stroke (52, 59); 1 epilepsy (31)	Anema et al.,[83] 2008
	France		1 stroke (72)	Auclair et al.,[63] 2009
	France		3 stroke (M: 59.66)	Cleret de Langavant,[62] 2009
	Brazil		61 CP (M: 8); 30 HC (M: 5)	Fontes et al.,[31] 2014

Table 2 (*Continued*)

Paradigm	Country	Instruments	Population (age)	Author
	Israel		1 TBI (22); 14 HC (adults)	Krasovsky et al.,[50] 2017
	Poland		50 ABI (M: 67.71); 50 HC (M: 68.71)	Razmus,[18] 2017
	Germany		37 stroke (M: 60.13); 19 HC (M: 59.7)	Dafsari et al.,[59] 2019
Body reading	UK	*Finger Strip Test*	12 Gerstmann syndrome (M: 54); 20 ABI (54.45)	Kinsbourne and Warrington,[82] 1962
	USA	*Oral Reading of Body Part Names*	1 dementia (50);	Coslett et al.,[11] 2002
Body-body matching	USA	*Matching Body Parts by Function*	1 dementia (50)	Coslett et al.,[11] 2002
	USA		55 stroke (M: 58); 18 HC (M: 47)	Schwoebel et al.,[20] 2004
	USA		70 stroke (M: 55); 18 HC	Schwoebel and Coslett,[7] 2005
	Brazil		61 CP (M: 8); 30 HC (M: 5)	Fontes et al.,[31] 2014
Object-body matching	Japan		1 stroke (66)	Suzuki et al.,[10] 1997
	USA		1 TBI (48)	Buxbaum and Coslett,[9] 2001
	USA	*Body Part and Object Association Task*	1 dementia (50)	Coslett et al.,[11] 2002
	USA		55 stroke (M: 58); 18 HC (M: 47)	Schwoebel et al.,[20] 2004
	USA	*Matching Body Parts to Objects Task*	70 stroke (M: 55); 18 HC	Schwoebel and Coslett,[7] 2005
	France	*Semantic Knowledge of Body Parts Task*	1 stroke (72)	Auclair et al.,[63] 2009
	Brazil		61 CP (M: 8); 30 HC (M: 5)	Fontes et al.,[31] 2014
	Israel		1 TBI (22); 14 HC (adults)	Krasovsky et al.,[50] 2017
	Poland		50 stroke (M: 67.71); 50 HC (M: 68.71)	Razmus,[18] 2018
	Italy		23 stroke (M: 62.58)	Di Vita et al.,[12] 2019
	Italy		90 HC (7-10); 37 HC (18-35)	Raimo et al.,[39] 2019
	Italy	*Object-Body Part Association Task*	33 CP (M: 7.69); 103 HC (M: 8.04)	Di Vita et al.,[32] 2020
	Italy		26 stroke (M: 56.07); 39 HC (M: 57.67)	Boccia et al.,[13] 2020
	Italy		64 stroke (M: 58.39); 41 HC (M: 58.39)	Raimo et al.,[15] 2022
Observation and imitation (meaningful gestures)	USA	*Imitation of Meaningful Gestures Task*	55 stroke (M: 58); 18 HC (M: 47)	Schwoebel et al.,[20] 2004
	Brazil		61 CP (M: 8); 30 HC (M: 5)	Fontes et al.,[31] 2014
Designating body parts	Poland	*Designating Body Parts task*	50 ABI (M: 67.71); 50 HC (M: 68.71)	Razmus,[18] 2017

ABI: acquired brain injury; CP: cerebral palsy; HC: healthy controls; M: mean age (years); MS: multiple sclerosis; TBI: traumatic brain injury.
Participants' age in years is shown in parentheses.
The instruments shown include all instruments with original names; in the majority of cases the task is replicated with minimal modifications, which does not add value to visual analysis.

Table 3 Prevalence of different profiles of subjects evaluated in the different constructs of body representation.

	Body schema	Body structural description	Body semantics
Adults			
Controls	922	542	246
Stroke	511	467	334
Pain	143	16	0
TBI	78	78	2
MS	59	0	0
Tumour	23	24	1
Amputees	18	18	0
ABI	4	52	0
Epilepsy	2	1	1
Gerstmann syndrome	0	12	12
Dementia	2	4	2
Children			
Controls	450	425	223
CP	124	94	94
Motor deficits	48	48	0
Total	2384	1781	915

ABI: acquired brain injury; CP: cerebral palsy; MS: multiple sclerosis; TBI: traumatic brain injury.

Table 4 Frequency of use of the different assessment paradigms.

	Number of participants
Body schema	
Left-right judgement	1658
Same/different matching	552
Observation and imitation (meaningless gestures)	603
Body structural description	
Body part localisation	896
Matching body parts by location	281
Visual construction of the body	962
Explicit body knowledge	157
Implicit body knowledge	125
Body semantics	
Body part naming	284
Body reading	13
Body-body matching	253
Object-body matching	826
Observation and imitation (meaningful gestures)	164
Designating body parts	100

and number of body parts targeted, the perspective of the body subjects are asked to point to, how stimuli are presented, how instructions are given, and even how errors are recorded.[7,18,19,22,25,31,62–65] Technological advances have enabled replication of an associative variant of this paradigm[66] using virtual reality headsets (Fig. 4), which have been tested in patients diagnosed with heterotopagnosia and healthy controls.[61]

Another paradigm is matching body parts by location.[11] In this task, the subject is presented with an image of a body

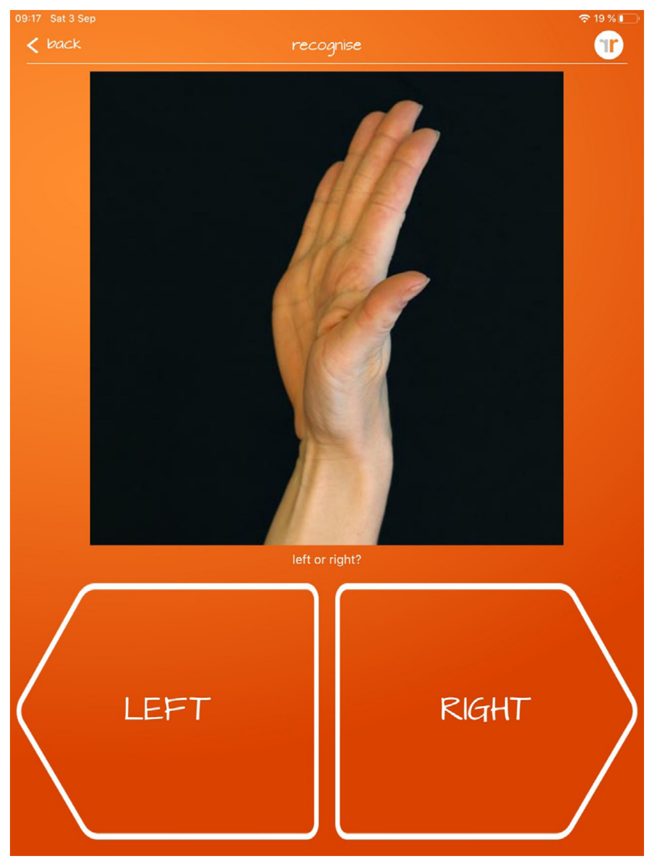

Figure 2 Trial of a left-right judgement protocol in the Hand Laterality Task (Recognise App[19,51]) for assessing body schema. The subject must respond as quickly as possible whether a left or right hand is shown. The image is original, and corresponds to a screenshot of one of the randomly presented stimuli on ''quick test'' mode.

Figure 3 Original stimuli from the same/different matching paradigm used in the Body Schema Task.[53] The subject must state whether 2 postures are the same or different.

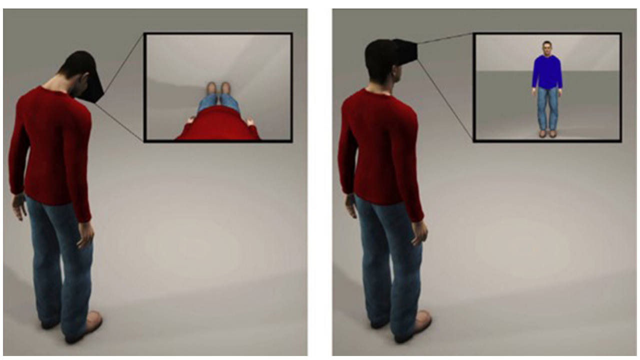

Figure 4 Experimental virtual reality task for assessing heterotopagnosia with a body part localisation paradigm, developed by Bassolino et al.,[61] to measure body structural description. The subject must indicate the number associated to different parts of a body (their own or somebody else's) from different perspectives (first or third person).

part and subsequently of another 3 body parts, and asked to select the one that best corresponds to the spatial continuation of the first image. In the study by Fontes et al.,[31] the literal instruction is ''Point to the figure of the body part that is nearer or continues the figure of XXX.'' Other authors used the questions ''is the wrist next to the shoulder or the elbow?''[63] or ''what body part is below the thigh?''[50]

Another paradigm is visual construction, with the example of the Body Representation Test developed by Daurat-Hmeljiak et al.,[26] or the Frontal Body-Evocation task,[65] which was originally designed for children but has been replicated by other authors in other clinical populations, including patients with stroke, cerebral palsy, and amputations.[12,13,15,24,64,65,67–70] In this task, participants are asked to construct a person's body or face based on an image of a body or face fragmented into its parts (Fig. 5). In a recent study, Di Vita et al.[13,32] developed a computerised version of this test, in which participants use a touchscreen to drag body parts into position one by one to construct the correct image. The advantage of this version is that it enables recording and coding of millimetric deviations from the accurate location of each body part. Human figure drawing tasks can also be considered a construction task, and are inexpensive to administer.[10,27,64,70]

Figure 5 Performance in the visual construction paradigm used in the Body Representation Test developed by Daurat-Hmeljiak et al.[26,65] for evaluating body structural description.

Finally, another paradigm is explicit body knowledge, in which participants are asked to distinguish between images of bodies in possible or impossible positions,[16,42] or whether body parts do or do not belong to the participant's own body.[53] Regarding body knowledge, we should also mention the only implicit processing paradigm, which involves pre-semantic knowledge of body structure.[19,71]

Evaluation of body semantics

One of the classical paradigms is naming tasks, in which participants are asked to verbally name the body parts shown in a series of photographs.[8,11,18,25,31,50,72] Another approach is reading paradigms; for instance, in the Oral Reading of Body Part Names task,[11] participants are asked to read 25 words corresponding to parts of the body, and correct and incorrect answers are recorded. Another of the more commonly used paradigms in BS assessment is object-body matching, in which subjects are asked to select the best association between an object and various body parts.[18,31,39] As shown in Fig. 6, the test may include foils based on contiguous or conceptually related body parts.[7,18]

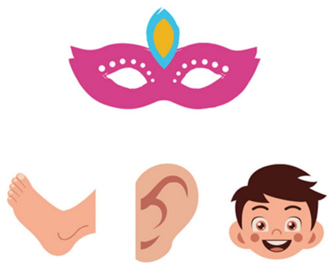

Figure 6 Stimuli from a trial of the Object-Body Part Association Task for evaluating body semantics. Subjects must indicate the body part most closely related to the object shown in the upper part of the slide. When testing children, the number of options shown in the lower part may be reduced to 2,[32] whereas 3 options are shown to adults.[18]

Another matching paradigm, in this case body-body matching, is the Matching Body Parts by Function task.[7,11,20,31] In this test, the examiner presents a screen with 4 images of different parts of the body (one at the top and 3 at the bottom of the screen), and subjects are required to decide which of the 3 bottom images is most closely related to the top image in terms of body function; subjects respond to a concrete association to the instruction ''Point to or say the name of the figure that is doing similar things as the figure of XXX.''[31] Finally, some articles used paradigms based on imitation of meaningful actions (eg, brushing hair, gesture of feeling cold), which constitute semantic mechanisms, or designating body parts, in which participants are presented with 22 photographs of body parts and asked to point to the ones named by the examiner.[18]

Discussion

The concept of body representation refers to a broad range of related concepts, which have overlapped in the scientific literature in recent years: BSch, body image, BS, BSD, description of BR, body map, etc.[6] These terms are not appropriately indexed in scientific databases, and return miscellaneous results from different healthcare areas. We propose a taxonomy of concepts based on the type of mechanism (implicit or explicit) and type of representation (perceptual or conceptual). Thus, BR could be categorised into BSch, BSD, and BS (Table 1).

Regarding the selection of assessment instruments, though a large range of tests have been described, the majority are variations on a single paradigm, and no standardised protocols exist. The main parameters showing differences are: the type of instructions, the form of sensory input of the instruction and the form of response, the types of stimuli presented, the number of series presented, the selection of measures for recording, the nomenclature of the tests, and the scoring system. In experimental tasks, the majority of instruments used to evaluate BR[7,18,31] are reported in a single patient[8,10,11,25,68] and have been replicated with sometimes contradictory results.[7,18]

We also observed a lack of consensus on certain essential matters, such as with the body part localisation paradigm, in which experts question whether or not the examiner should name the body part before asking the subject to point to it[18,59] (this is one of the main criticisms that can be made of the only subtests validated in the Spanish adult population),[33] or whether 2 or 3 possible responses should be shown in matching paradigms.[18,32] In any case, it seems reasonable to minimise verbal commands in body part localisation tasks, as suggested by Dafsari et al.[59] and Razmus,[18] with a view to avoiding confusion between BDS and BS. If this recommendation is not followed, then 5 of the 7 subtests of the Barcelona Test 2 would amount to assessments of BS. It also seems inappropriate to present only 2 possible responses, as this may lead to results being influenced by chance; in the light of this, the versions presented by Auclair et al.[63] seem interesting, as they eliminate the multiple-choice responses from the stimulus presentation, forcing the subject to answer freely without visual cues.

In general terms, the literature is better developed in such countries as the United States and Italy,[7,18,22,25,31] with BR research being conducted by a small number of study groups, suggesting that the field may benefit from other cultural perspectives that may influence this research. In Spain, the Barcelona Test 2 subtests were validated in 2019; however, the publication was not identified in the literature review, hence their exclusion from Table 2.[33] In our opinion, their inclusion would provide one test of BSch (imitation of pseudogestures), one test of BSD (finger recognition), and 5 tests of BS (visual/verbal naming of body parts, verbal comprehension of body parts, left/right orientation, pantomime of object-use, and symbolic gestures of communication), which are validated in the Spanish language (336 healthy adults aged 20-87 years); this is highly relevant for their inclusion in routine examination. In general, there is a tendency for authors to use classical instruments[7,17,18,31]; nonetheless, there is currently no consensus on the administration protocol in this assessment, and these studies therefore present great differences in methodology. In fact, there are numerous examples[31] in which the same test is given different names, and could be classified under a single paradigm, simplifying searches.

To that end, the most promising future perspective would include selecting stimuli (body parts) according to a scientific criterion, such as frequency of use or the results of factor analysis, and establishing the names of tasks and specifying variants in the procedure. In addition to standardisation efforts, recent years have seen a computerisation of tasks with an emphasis on measurement precision and replicability. Despite this, few studies have used a fully computerised test battery.[13,15,32]

The inclusion of BR instruments in neuropsychological assessment protocols would enable deeper understanding of the relationship between such cognitive processes as language and motor action,[73–77] among others. This would also enable study of integrated body-mind therapies, which aim to improve awareness of the body and movement, or embodied cognition, and may moderate executive functions and memory.[78–80] The creation of a specific, sensitive instrument for assessing BR may lead to a clinically useful screening test for pathological ageing and such other conditions as cerebrovascular lesions, enabling timely prevention with therapies that stimulate BR, and promote health and quality of life in patients with impaired BR.[16]

Table 5 Proposed clinical questions to explore different components of body representation.

Construct	Clinical questions	Responses	Paradigm
BSch	How is it positioned?	Posture	Left-right judgement Same/different matching Observation and imitation (meaningless gestures)
BSD	Where is it?	Position	Body part localisation Matching body parts by location Visual construction of the body
	What does it look like? Which is it?	Shape	Explicit body knowledge Implicit body knowledge
BS	What is it? What is it called?	Semantic	Body part naming Reading Designating body parts Observation and imitation (meaningful gestures)
	What is it used with? What is it for?	Affordance*	Object-body matching
	How does it work? How is it used?	Mechanics	Body-body matching

BSD: body structural description; BSch: body schema; BS: body semantics.
Note: questions refer to the body or parts of the body.
* For a review of the term affordance, we recommend the study by Osiurak et al.[88]

In this regard, Table 5 presents a series of screening questions for assessing different responses about the body and related to BR. Despite the main strengths of our study, which extensively gathers all cognitive instruments assessing BR and classifies them into 14 paradigms, it does present several limitations. These include the fact that we did not filter according to type of article (eg, randomised clinical trials, trials with 2 groups, etc), which hinders risk-of-bias analysis and the acquisition of synthesis measures in accordance with the PRISMA criteria[34]; although this was an exploratory study, these analyses would have enabled better control for possible biases. We also did not establish a working criterion for excluding articles with paediatric populations, although we filtered out these studies in the preliminary PubMed search as the number of results was unmanageable. Furthermore, the study was not registered in advance, which may compromise the transparency of the evidence.

Conclusions

We observed considerable terminological confusion, and therefore propose a taxonomy of concepts based on the type of mechanism (implicit or explicit) and the type of representation (perceptual or conceptual).

Many studies used certain classical instruments, with various levels of modification, although no validated, evidence-based consensus protocol has been established.

A BR evaluation protocol should include, as a minimum, left-right judgement, body part localisation, and object-body matching paradigms.

Appropriate assessment instruments should be developed in the light of the fact that altered BR is common to numerous diseases.

We propose that the names of the paradigms mentioned be treated as a consensus for communication in the replication of studies into BR, and that the term body representation be popularised as a supra-ordinal category to the terms BSch, BSD, and BS.

To our knowledge, ours is the first Spanish-language review of assessment instruments for BR.

Funding

This study has received no external funding of any kind.

Declaration of competing interest

The authors have no financial or personal relationships with other persons or organisations which could create conflicts of interest with regard to this article.

Acknowledgements

The authors thank Jordi Peña-Casanova for sharing the normative data for the Programa Integrado de Exploración Neuropsicológica-Barcelona Test 2. We also thank Rocío Polanco, Patricia Martín, Roberta Ghedina, and Magdalena Razmus.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.nrleng.2025.09.003.

References

1. Head H, Holmes G. Sensory disturbances from cerebral lesions. Brain. 1911;34(2-3):102—254, http://dx.doi.org/10.1016/S0140-6736(01)64640-3.

2. Pick A. Störung der Orientierung am Eigenen Körper. Psychologische Forschung. 1922;2:303—18, http://dx.doi.org/10.1007/BF00410392.
3. Tessari A, Tsakiris M, Borghi AM, Serino A. The sense of body: a multidisciplinary approach to body representation. Neuropsychologia. 2010;48(3):643—4, http://dx.doi.org/10.1016/j.neuropsychologia.2009.12.004.
4. Riva G. The neuroscience of body memory: from the self through the space to the others. Cortex. 2018;104:241—60, http://dx.doi.org/10.1016/j.cortex.2017.07.013.
5. Tamè L, Azañón E, Longo MR. A conceptual model of tactile processing across body features of size, shape, side, and spatial location. Front Psychol. 2019;10:291, http://dx.doi.org/10.3389/fpsyg.2019.00291.
6. de Vignemont F. Body schema and body image—Pros and cons. Neuropsychologia. 2010;48(3):669—80, http://dx.doi.org/10.1016/j.neuropsychologia.2009.09.022.
7. Schwoebel J, Coslett HB. Evidence for multiple, distinct representations of the human body. J Cognit Neurosci. 2005;17(4):543—53, http://dx.doi.org/10.1162/0898929053467587.
8. Sirigu A, Grafman J, Bressler K, Sunderland T. Multiple representations contribute to body knowledge processing: evidence from a case of autotopagnosia. Brain. 1991;114(1):629—42, http://dx.doi.org/10.1093/brain/114.1.629.
9. Buxbaum LJ, Branch Coslett H. Specialised structural descriptions for human body parts: evidence from autotopagnosia. Cognit Neuropsychol. 2001;18(4):289—306, http://dx.doi.org/10.1080/02643290126172.
10. Suzuki K, Yamadori A, Fuji T. Category-specific comprehension deficit restricted to body parts. Neurocase. 1997;3(3):193—200, http://dx.doi.org/10.1080/13554799708404054.
11. Coslett HB, Saffran EM, Schwoebel J. Knowledge of the human body: a distinct semantic domain. Neurology. 2002;59(3):357—63, http://dx.doi.org/10.1212/WNL.59.3.357.
12. Di Vita A, Palermo L, Boccia M, Guariglia C. Topological map of the body in post-stroke patients: lesional and hodological aspects. Neuropsychology. 2019;33(4):499—507, http://dx.doi.org/10.1037/neu0000536.
13. Boccia M, Raimo S, Di Vita A, Battisti A, Matano A, Guariglia C, et al. Topological and hodological aspects of body representation in right brain damaged patients. Neuropsychologia. 2020;148, http://dx.doi.org/10.1016/j.neuropsychologia.2020.107637.
14. Berlucchi G, Aglioti S. The body in the brain: neural bases of corporeal awareness. Trends Neurosci. 1997;20(12):560—4, http://dx.doi.org/10.1016/S0166-2236(97)01136-3.
15. Raimo S, Boccia M, Di Vita A, Iona T, Cropano M, Ammendolia A, et al. Body representation alterations in patients with unilateral brain damage. J Int Neuropsychol Soc. 2022;28(2):130—42, http://dx.doi.org/10.1017/S1355617721000151.
16. Baumard J, Lesourd M, Remigereau C, Lucas C, Jarry C, Osiurak F, et al. Imitation of meaningless gestures in normal aging. Aging Neuropsychol Cognit. 2020;27(5):729—47, http://dx.doi.org/10.1080/13825585.2019.1674773.
17. Raimo S, Di Vita A, Boccia M, Iona T, Cropano M, Gaita M, et al. The body across the lifespan: on the relation between interoceptive sensibility and high-order body representations. Brain Sci. 2021;11(4):493, http://dx.doi.org/10.3390/brainsci11040493.
18. Razmus M. Body representation in patients after vascular brain injuries. Cogn Process. 2017;18(4):359—73, http://dx.doi.org/10.1007/s10339-017-0831-8.
19. Lane D, Tessari A, Ottoboni G, Marsden J. Body representation in people with apraxia post Stroke— an observational study. Brain Inj. 2021:1—8, http://dx.doi.org/10.1080/02699052.2021.1880637.
20. Schwoebel J, Buxbaum LJ, Branch Coslett H. Representations of the human body in the production and imitation of complex movements. Cognit Neuropsychol. 2004;21(2-4):285—98, http://dx.doi.org/10.1080/02643290342000348.
21. Buxbaum LJ, Giovannetti T, Libon D. The role of the dynamic body schema in praxis: evidence from primary progressive apraxia. Brain Cognit. 2000;44(2):166—91, http://dx.doi.org/10.1006/brcg.2000.1227.
22. Semenza C, Goodglass H. Localization of body parts in brain injured subjects. Neuropsychologia. 1985;23(2):161—75, http://dx.doi.org/10.1016/0028-3932(85)90101-0.
23. Coslett HB. Evidence for a disturbance of the body schema in neglect. Brain Cognit. 1998;37(3):527—44, http://dx.doi.org/10.1006/brcg.1998.1011.
24. Di Vita A, Palermo L, Piccardi L, Di Tella J, Propato F, Guariglia C. Body representation alterations in personal but not in extrapersonal neglect patients. Appl Neuropsychol Adult. 2017;24(4):308—17, http://dx.doi.org/10.1080/23279095.2016.1174866.
25. Ogden JA. Autotopagnosia: occurrence in a patient without nominal aphasia and intact ability to pint to parts of animals and objects. Brain. 1985;108(4):1009—22, http://dx.doi.org/10.1093/brain/108.4.1009.
26. Daurat-Hmeljiak C, Stambak M, Berges J. Il test dello schema corporeo. Una prova di conoscenza e costruzione dell'immagine del corpo. Florence, Italy: Organizzazioni Speciali; 1978.
27. Jiménez SB. Estudio evolutivo del esquema corporal a través de la prueba de Daurat-Hmeljak. Stambak y Berges. Universidad Complutense de Madrid (Spain); 1980.
28. Benton AL, Menefee FL. Handedness and right-left discrimination. Child Dev. 1957;28(2):237—42, http://dx.doi.org/10.2307/1125884.
29. Parsons LM. Imagined spatial transformations in the visual discrimination of left and right parts of the h u m a n body. San Diego: Doctoral Disertation at the Department of Psychology, University of California; 1983. p. 5.
30. Parsons LM. Imagined spatial transformation of one's body. J Exp Psychol General. 1987;116(2):172—91, http://dx.doi.org/10.1037/0096-3445.116.2.172.
31. Fontes PLB, Moura R, Haase VG. Evaluation of body representation in children with hemiplegic cerebral palsy: toward the development of a neuropsychological test battery. Psychol Neurosci. 2014;7(2):139—49, http://dx.doi.org/10.3922/j.psns.2014.019.
32. Di Vita A, Cinelli MC, Raimo S, Boccia M, Buratin S, Gentili P, et al. Body representations in children with cerebral palsy. Brain Sci. 2020;10(8):1—12, http://dx.doi.org/10.3390/brainsci10080490.
33. Test Barcelona 2. Accedido el 01/08/2022. [Accessed 1 August 2022]. Available from: https://test-barcelona.com/.
34. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ. 2021:n71, http://dx.doi.org/10.1136/bmj.n71.
35. Nikishina VB, Lazarenko VA, Petrash EA, Akhmetzyanova AI. Impairments to body image in meningioma of the parietal-occipital area. Neurosci Behav Physiol. 2018;48(4):399—403, http://dx.doi.org/10.1007/s11055-018-0577-5.
36. Curtze C, Otten B, Postema K. Effects of lower limb amputation on the mental rotation of feet. Exp Brain Res. 2010;201(3):527—34, http://dx.doi.org/10.1007/s00221-009-2067-z.
37. Corradi-Dell'Acqua C, Tessari A. Is the body in the eye of the beholder? Visual processing of bodies in individuals with anomalous anatomical sensory and motor features. Neuropsychologia. 2010;48(3):689—702, http://dx.doi.org/10.1016/j.neuropsychologia.2009.11.029.

38. Coslett HB, Medina J, Kliot D, Burkey A. Mental motor imagery and chronic pain: The foot laterality task. J Int Neuropsychol Soc. 2010;16(4):603—12, http://dx.doi.org/10.1017/S1355617710000299.
39. Raimo S, Iona T, Di Vita A, Boccia M, Buratin S, Ruggeri F, et al. The development of body representations in school-aged children. Appl Neuropsychol Child. 2021;10(4):327—39, http://dx.doi.org/10.1080/21622965.2019.1703704.
40. Arzy S, Thut G, Mohr C, Michel CM, Blanke O. Neural basis of embodiment: distinct contributions of temporoparietal junction and extrastriate body area. J Neurosci. 2006;26(31):8074—81, http://dx.doi.org/10.1523/JNEUROSCI.0745-06.2006.
41. Blanke O. Linking out-of-body experience and self processing to mental own-body imagery at the temporoparietal junction. J Neurosci. 2005;25(3):550—7, http://dx.doi.org/10.1523/JNEUROSCI.2612-04.2005.
42. Butti N, Montirosso R, Giusti L, Piccinini L, Borgatti R, Urgesi C. Early brain damage affects body schema and person perception abilities in children and adolescents with spastic diplegia. Neural Plast. 2019;2019, http://dx.doi.org/10.1155/2019/1678984.
43. Easton S, Blanke O, Mohr C. A putative implication for fronto-parietal connectivity in out-of-body experiences. Cortex. 2009;45(2):216—27, http://dx.doi.org/10.1016/j.cortex.2007.07.012.
44. Overney LS, Arzy S, Blanke O. Deficient mental own-body imagery in a neurological patient with out-of-body experiences due to cannabis use. Cortex. 2009;45(2):228—35, http://dx.doi.org/10.1016/j.cortex.2008.02.005.
45. Zacks J. A parametric study of mental spatial transformations of bodies. NeuroImage. 2002;16(4):857—72, http://dx.doi.org/10.1006/nimg.2002.1129.
46. Cooper LA, Shepard RN. Mental transformations in the identification of left and right hands. J Exp Psychol Human Percept Perform. 1975;1(1), http://dx.doi.org/10.1037/0096-1523.1.1.48.
47. Parsons LM, Gabrieli JDE, Phelps EA, Gazzaniga MS. Cerebrally lateralized mental representations of hand shape and movement. J Neurosci. 1998;18(16):6539—48, http://dx.doi.org/10.1523/JNEUROSCI.18-16-06539.1998.
48. Parsons LM. Temporal and kinematic properties of motor behavior reflected in mentally simulated action. J Exp Psychol Human Percept Perform. 1994;24(4):709, http://dx.doi.org/10.1037/0096-1523.20.4.709.
49. Parsons LM. Imagined spatial transformations of one's hands and feet. Cognit Psychol. 1987;(19):178—241, http://dx.doi.org/10.1016/0010-0285(87)90011-9.
50. Krasovsky T, Landa J, Bar O, Jaana A-A, Livny A, Tsarfaty G, et al. Functional plasticity in the absence of structural change: apraxia and body scheme disorder 10 years after childhood brain injury. J Child Neurol. 2017;32(5):505—11, http://dx.doi.org/10.1177/0883073816688833.
51. Pelletier R, Bourbonnais D, Higgins J, Mireault M, Danino MA, Harris PG. Left right judgement task and sensory, motor, and cognitive assessment in participants with wrist/hand pain. Rehabil Res Pract. 2018;2018, http://dx.doi.org/10.1155/2018/1530245.
52. Amesz S, Tessari A, Ottoboni G, Marsden J. An observational study of implicit motor imagery using laterality recognition of the hand after stroke. Brain Inj. 2016;30(8):999—1004, http://dx.doi.org/10.3109/02699052.2016.1147600.
53. Olgiati E, Maravita A, Spandri V, Casati R, Ferraro F, Tedesco L, et al. Body schema and corporeal self-recognition in the alien hand syndrome. Neuropsychology. 2017;31(5):575—84, http://dx.doi.org/10.1037/neu0000359.
54. Reed CL, Farah MJ. The psychological reality of the body schema: a test with normal participants. J Exp Psychol Human Percept Perform. 1995;21(2):334, http://dx.doi.org/10.1037/0096-1523.21.2.334.
55. Sirigu A, Duhamel J-R, Cohen L, Pillon B, Dubois B, Agid Y. The mental representation of hand movements after parietal cortex damage. Science. 1996;273(5281):1564—8, http://dx.doi.org/10.1126/science.273.5281.1564.
56. Goldenberg G. Imitation and matching of hand and finger postures. NeuroImage. 2001;14(1):S132—136, http://dx.doi.org/10.1006/nimg.2001.0820.
57. Goldenberg G. Imitating gestures and manipulating a mannikin—-The representation of the human body in ideomotor apraxia. Neuropsychologia. 1995;33(1):63—72, http://dx.doi.org/10.1016/0028-3932(94)00104-W.
58. Goldenberg G. Defective imitation of gestures in patients with damage in the left or right hemispheres. J Neurol Neurosurg Psychiatry. 1996;61(2):176—80, http://dx.doi.org/10.1136/jnnp.61.2.176.
59. Dafsari HS, Dovern A, Fink GR, Weiss PH. Deficient body structural description contributes to apraxic end-position errors in imitation. Neuropsychologia. 2019;133:107150, http://dx.doi.org/10.1016/j.neuropsychologia.2019.107150.
60. Felician O, Ceccaldi M, Didic M, Thinus-Blanc C, Poncet M. Pointing to body parts: a double dissociation study. Neuropsychologia. 2003;41(10):1307—16, http://dx.doi.org/10.1016/S0028-3932(03)00046-0.
61. Bassolino M, Bouzerda-Wahlen A, Moix V, Bellmann A, Herbelin B, Serino A, et al. You or me? Disentangling perspectival, perceptual, and integrative mechanisms in heterotopagnosia. Cortex. 2019;120:212—22, http://dx.doi.org/10.1016/j.cortex.2019.05.017.
62. Cleret de Langavant L, Trinkler I, Cesaro P, Bachoud-Lévi A-C. Heterotopagnosia: When I point at parts of your body. Neuropsychologia. 2009;47(7):1745—55, http://dx.doi.org/10.1016/j.neuropsychologia.2009.02.016.
63. Auclair L, Noulhiane M, Raibaut P, Amarenco G. Where are your body parts? A pure case of heterotopagnosia following left parietal stroke. Neurocase. 2009;15(6):459—65, http://dx.doi.org/10.1080/13554790902911642.
64. Di Vita A, Palermo L, Piccardi L, Guariglia C. Peculiar body representation alterations in hemineglect: a case report. Neurocase. 2015;21(6):697—706, http://dx.doi.org/10.1080/13554794.2014.974620.
65. Guariglia C, Piccardi L, Puglisi Allegra MC, Traballesi M. Is autotopoagnosia real? EC says yes. A case study. Neuropsychologia. 2002;40(10):1744—9, http://dx.doi.org/10.1016/S0028-3932(02)00013-1.
66. Semmes J, Weinstein S, Ghent G, Meyer JS, Teuber H-L. Correlates of impaired orientation in personal and extrapersonal space. Brain. 1963;86(4):747—72, http://dx.doi.org/10.1093/brain/86.4.747.
67. Palermo L, Di Vita A, Piccardi L, Traballesi M, Guariglia C. Bottom-up and top-down processes in body representation: a study of brain-damaged and amputee patients; 24799290. Neuropsychology. 2014;28(5):772—81, http://dx.doi.org/10.1037/neu0000086.
68. Canzano L, Piccardi L, Bureca I, Guariglia C. Mirror writing resulting from an egocentric representation disorder: a case report. Neurocase. 2011;17(5):447—60, http://dx.doi.org/10.1080/13554794.2010.532143.
69. Guariglia C, Antonucci G. Personal and extrapersonal space: a case of neglect dissociation. Neuropsychologia. 1992;30(11):1001—9, http://dx.doi.org/10.1016/0028-3932(92)90051-M.
70. Marangolo P, Piccardi L, Rinaldi MC. Dissociation between personal and extrapersonal neglect in a crossed aphasia study. Neurocase. 2003;9(5):414—20, http://dx.doi.org/10.1076/neur.9.5.414.16554.
71. Ottoboni G, Tessari A, Cubelli R, Umiltà C. Is handedness recognition automatic? A Study using a Simon-like paradigm.

J Exp Psychol Human Percept Perform. 2005;31(4):778—89, http://dx.doi.org/10.1037/0096-1523.31.4.778.
72. Denes G, Cappelletti JY, Zilli T, Dalla Porta F, Gallana A. A category-specific deficit of spatial representation: the case of autotopagnosia. Neuropsychologia. 2000;38(4):345—50, http://dx.doi.org/10.1016/S0028-3932(99)00101-3.
73. Borghi AM, Glenberg AM, Kaschak MP. Putting words in perspective. Memory Cognit. 2004;32(6):863—73, http://dx.doi.org/10.3758/BF03196865.
74. Glenberg AM, Kaschak MP. Grounding language in action. Psychonomic Bull Rev. 2002;9(3):558—65, http://dx.doi.org/10.3758/BF03196313.
75. Pulvermüller F. Brain mechanisms linking language and action. Nat Rev Neurosci. 2005;6(7):576—82, http://dx.doi.org/10.1038/nrn1706.
76. Rueschemeyer S-A, Pfeiffer C, Bekkering H. Body schematics: on the role of the body schema in embodied lexical—semantic representations. Neuropsychologia. 2010;48(3):774—81, http://dx.doi.org/10.1016/j.neuropsychologia.2009.09.019.
77. Shebani Z, Pulvermüller F. Flexibility in Language action interaction: the influence of movement type. Front Hum Neurosci. 2018;12:252, http://dx.doi.org/10.3389/fnhum.2018.00252.
78. Ren F-F, Chen F-T, Zhou W-S, Cho Y-M, Ho T-J, Hung T-M, et al. Effects of Chinese mind-body exercises on executive function in middle-aged and older adults: a systematic review and meta-analysis. Front Psychol. 2021;12:656141, http://dx.doi.org/10.3389/fpsyg.2021.656141.
79. Koziol LF, Budding DE, Chidekel D. From movement to thought: executive function, embodied cognition, and the cerebellum. Cerebellum. 2012;11(2):505—25, http://dx.doi.org/10.1007/s12311-011-0321-y.
80. Ullmann G, Li Y, Ray MA, Lee ST. Study protocol of a randomized intervention study to explore effects of a pure physical training and a mind—body exercise on cognitive executive function in independent living adults age 65—85. Aging Clin Exp Res. 2021;33(5):1259—66, http://dx.doi.org/10.1007/s40520-020-01633-w.
81. García JS. Esquema corporal y deficiencia motriz. Anuario de psicología/The UB J Psychol. 1977:95—112.
82. Kinsbourne M, Warrington EK. A study of finger agnosia. Brain. 1962;85(1):47—66, http://dx.doi.org/10.1093/brain/85.1.47.
83. Anema HA, Kessels RPC, De Haan EHF, Kappelle LJ, Leijten FS, Van Zandvoort MJE, et al. Differences in finger localisation performance of patients with finger agnosia. Neuroreport. 2008;19(14):1429—33, http://dx.doi.org/10.1097/WNR.0b013e32830e017b.
84. Rusconi E, Tamè L, Furlan M, Haggard P, Demarchi G, Adriani M, et al. Neural correlates of finger gnosis. J Neurosci. 2014;34(27):9012—23, http://dx.doi.org/10.1523/JNEUROSCI.3119-13.2014.
85. Rusconi E, Gonzaga M, Adriani M, Braun C, Haggard P. Know thyself: behavioral evidence for a structural representation of the human body. PLoS One. 2009;4(5):e5418, http://dx.doi.org/10.1371/journal.pone.0005418.
86. Thurm BE, Matoso A, Diaz AC, Paschoalini C, Neves E, Tuunelis R, et al. Chronic pain effect on body schema and neuropsychological performance in athletes: a pilot study. PerceptMotSkills. 2013;116(2):544—53, http://dx.doi.org/10.2466/15.27.PMS.116.2.544-553.
87. Ronchi R, Bassolino M, Viceic D, Bellmann A, Vuadens P, Blanke O, et al. Disownership of body parts as revealed by a visual scale evaluation. An observational study. Neuropsychologia. 2020;138, http://dx.doi.org/10.1016/j.neuropsychologia.2020.107337.
88. Osiurak F, Rossetti Y, Badets A. What is an affordance? 40 years later. Neurosci Biobehav Rev. 2017;77:403—17, http://dx.doi.org/10.1016/j.neubiorev.2017.04.014.