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Citation for published version:
Brusa, F, Kretzschmar, L, Magnani, FG, Turner, G, Garraffa, M & Sedda, A 2021, 'Talking with hands: body representation in British Sign Language users', *Experimental Brain Research*, vol. 239, no. 3, pp. 731-744.
https://doi.org/10.1007/s00221-020-06013-4

Digital Object Identifier (DOI):
10.1007/s00221-020-06013-4

Document Version:
Peer reviewed version

Published In:
Experimental Brain Research

Talking with hands: body representation in British Sign Language users.

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Word count: 6066

Tables: 1

Figures: 3

Abstract

Body representation (BR) refers to the mental representation of motor, sensory, emotional and semantic information about the physical body. This cognitive representation is used in our everyday life, continuously, even though most of the time we do not appreciate it consciously. In some cases, BR is vital to be able to communicate. A crucial feature of signed languages (SLs), for instance, is that body parts such as hands are used to communicate. Nevertheless, little is known about BR in SL: is the communicative function of the body overwriting the physical constraints? Here, we explored this question by comparing twelve British Sign Language (BSL) learners to seventeen tango dancers (body expertise but not for communication) and fourteen control subjects (no special body expertise). We administered the Body Esteem Scale (BES), the Hand Laterality Task (HLT) and the Mental Motor Chronometry (MMC). In order to control for visual imagery, we administered ad hoc control tasks. We did not identify parameters able to differentiate between SL users and the other groups, whereas the more implicit parameters distinguished clearly tango dancers from controls. Importantly, neither tasks on visual imagery nor the BES revealed differences. Our findings offer initial evidence that linguistic use of the body not necessarily influences the cognitive components we explored of body representation.

Keywords: British Sign Language; Body Representation; Body Schema; Motor Imagery; Mental Imagery; Motor skills; Expertise.

Introduction

Body representation (BR) (Holmes and Spence 2004) includes a variety of aspects that encompass the knowledge we have about bodies, the emotions, and attitudes directed towards one's own body, the structural properties of bodies parts and action-related representations (Longo et al. 2010). These latter representations, sometimes globally named Body Schema (BS) (de Vignemont 2010; 2011), play a pivotal role not only in producing accurate movement to interact with the environment, but also in understanding other individuals' actions (Schwoebel et al. 2004). Another component of BR in classic dichotomic models is Body Image (BI) (de Vignemont 2010): in other words, all the other representations of the body unrelated to action, but close to perception, abstract representations, and emotions. While this dichotomy has been recently criticized, and some models propose that the notion of a difference between the BS and the BI does not hold anymore (Longo et al. 2010), recent work has also highlighted the importance of these concepts in terms of developing a framework for BR that is focused on functional differences in how we imagine our bodies (Pitron and de Vignemont 2017).

Independently of the theoretical reference adopted, it is undeniable that the cognitive skill of imagining actions – in other words, the ability to access a mental representation of movements and postures – is a fundamental ability to carry out everyday tasks effectively. As such, Motor Imagery (MI) (Parsons, 1987; 1994), the mental recollection of a motor act without any overt movement (Rumiati et al. 2010), has been proven extremely useful to understand how physical constraints impact on mental representations of the body in action. For instance, when judging a body part laterality (i.e. hand), individuals mentally rotate their body part to match it with the target stimulus, even when not explicitly instructed to do so (Parsons 1994). Not by chance, changes in the ability to move (Fiori et al. 2013; Fiori et al. 2014; Scarpina et al. 2019; Sedda et al. 2019) and the loss of limbs (André et al. 2001) impact on how we represent our body.

Not only sudden or degenerative physical impairments can change the representation of the body, but, importantly, experience can do so too. In healthy individuals, expertise level (related to individual skills and experiences) can affect performance, as seen for instance in professional dancers (Ramsay and Riddoch 2001; Jola et al. 2011) or magicians (Cocchini et al. 2018) who have better proprioceptive skills for the hand. Not only proprioception, but also kinematic parameters are influenced by practice of skilled actions such as performing magic tricks (Cavina-Pratesi et al. 2011). Finally, changes related to expertise can also be observed at the cortical level, in the somatosensory cortex, in individuals with special manual expertise, such as string musicians (Elbert et al. 1995) and Braille readers (Pascual-Leone and Torres 1993; Sterr et al. 1998).

In MI tasks, special manual expertise causes an increase (or decrease) in the strength of the relationship between real movement time and imagined movement time (Guillot et al., 2012; Guillot et al., 2009). Furthermore, the so-called "action-sentence compatibility" demonstrates that sentence comprehension facilitates motor responses if it implies a movement in the same direction (Aravena et al. 2010; Diefenbach et al. 2013; Gianelli et al. 2011; Glenberg and Kaschak 2002; van Dam and Desai 2017). Hearing sentences that describe actions can also influence the activity of the motor system (Buccino et al.2005; Tettamanti et al. 2005). This evidence shows an interconnection between language and action.

A solid example of the interconnection between the sensory-motor system and language is provided by natural Sign Languages (SLs), as SLs are based on the use of the body and of spatial coordinates for everyday communication (Cormier et al. 2015; Dachkovsky et al. 2018). Some studies attest that SLs enhance non-linguistic abilities such as mental rotation and Visual Imagery (VI) (Emmorey et al. 1993; Talbot and Haude 1993). Results are read in terms of involvement of visuo-spatial abilities in SLs. However, less is known about changes in the mental representation of the body in action when the body is used to communicate. One open question is whether the communicative function of the body overwrites the physical constraints, eliminating classic effects that can be seen in MI tasks such as the effect of biomechanical constraints (Parsons 1987; 1994). Typically, individuals require more time to imagine a posture they cannot reach easily with their physical body (Parsons 1987; 1994). This constraint is lost when the physical body is impaired (Fiori et al. 2013; Fiori et al. 2014). In the case of SL, the physical body is not impaired, rather is 'super-used', as happens with professional dancers (Jola et al. 2011; Ramsay and Riddoch 2001), string musicians (Elbert et al. 1995) , Braille readers (Pascual-Leone and Torres 1993; Sterr et al. 1998) and magicians (Cavina-Pratesi et al. 2011; Cocchini et al. 2018). However, at present, it is unknown if this different functionality of the body changes the mental representation of it.

To identify if differences exist, and if they are related to the communicative use of the body or to special expertise, we compared BSL users' performance with that of a group of tango dancers, a discipline where the whole body contributes to the performance, and a control group without specific training concerning the use of their body.

To our knowledge, there is no clear-cut way to identify who will become a proficient SL user when learning a SL as a second language. We hypothesize that BR in its multiple components (motor- and sensory-related) – i.e. a relevant non-linguistic, cognitive index – might explain the different proficiency of individuals learning and using BSL. Like dancers and magicians, SL users who become proficient might have a better representation of their body and hence more successfully use it for communication. Hence, data from our study are not only of interest in terms of advancing theoretical knowledge on BR in different populations but could also provide a new venue to integrate knowledge from cognitive psychology into training of new professionals.

Methods

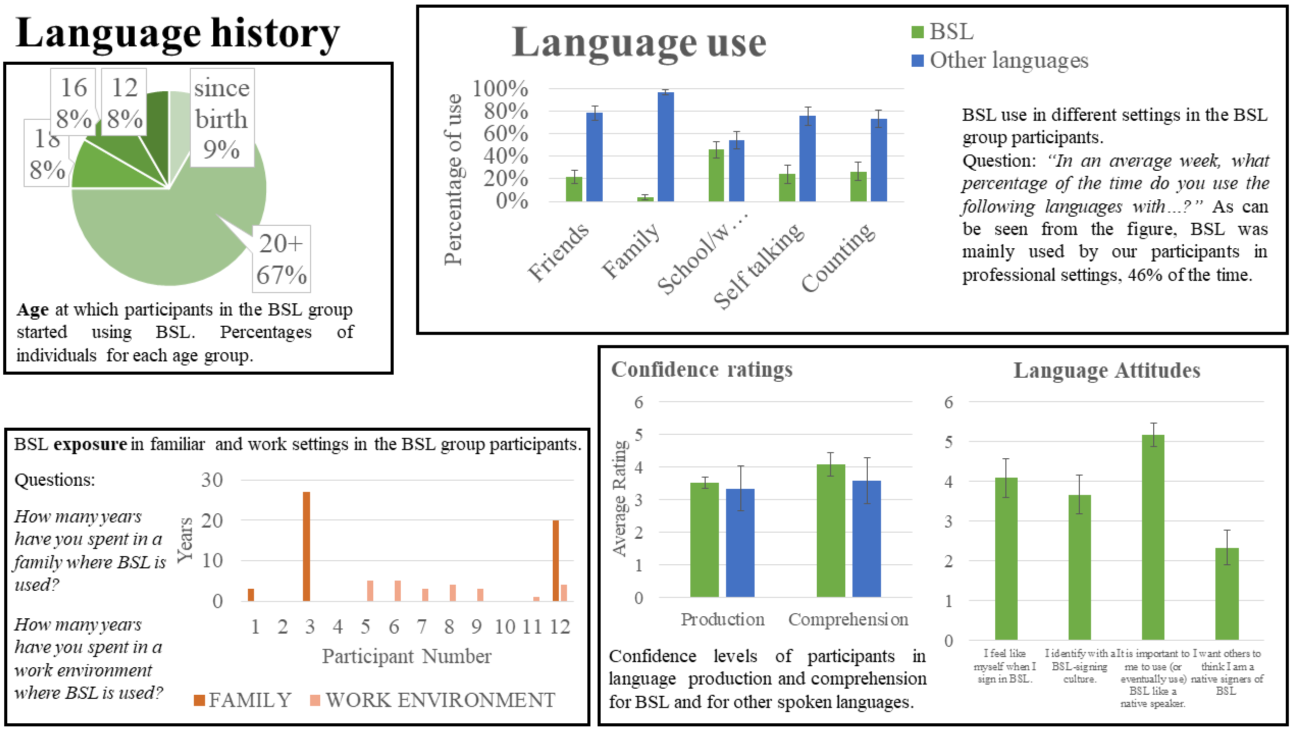
Participants

Forty-three individuals were recruited for this study, through word of mouth, personal and professional contacts at Heriot-Watt University. Twelve hearing British Sign Language (BSL) learners participated in the study (n= 12; mean age ± SD: 39.9 ± 12.1; mean education ± SD: 16.5 ± 1.8; 11 females). Their performance has been compared to that of tango dancers (n=17; mean age ± SD: 43.5 ± 15.9; mean education ± SD: 18.6 ± 3.4; 11 females; dancing since 7.6 years on average and 4.2 hours a week on average), and controls (no expertise in any of the above) (n=14; mean age ± SD: 27 ± 9.1; mean education ± SD: 15.8 ± 3.2; 12 females).

Inclusion criteria were absence of any sensory, neurological or psychiatric impairment. Only right-handed participants were enrolled, selected using the Edinburgh Handedness Inventory short version (Veale 2014), a self-report questionnaire with 4 items (writing, throwing, use of the toothbrush and of the spoon). A Laterality Quotient (LQ) is calculated as the sum of the items score divided by the total number of the items (Veale 2014). A cut off of 61 indicates right-handedness (Veale 2014). We only included right-handers to avoid confounding effects, due to the putative different cerebral lateralization of cognitive functions in left-handers and the different presence of cognitive effects in this sub-population (Ionta and Blanke 2009).

A British Sign Language Profile questionnaire was administered to BSL users, adapted from the Bilingual Language Profile (Birdsong et al. 2012) (Appendix 1). The questionnaire allows the expertise of the participants to be identified in some detail, with all of them reporting high level of proficiency in both production and comprehension of the language (Figure 1 BSL Profile Results).

Informed consent was obtained prior to participation. The study was designed according to the ethical standards of the Declaration of Helsinki and received approval from the local ethical committee at Heriot-Watt University (approval number: 2016-170; 2017-446).


Language history

Age at which participants in the BSL group started using BSL. Percentages of individuals for each age group.

Language use

BSL use in different settings in the BSL group participants.
Question: *"In an average week, what percentage of the time do you use the following languages with…?"* As can be seen from the figure, BSL was mainly used by our participants in professional settings, 46% of the time.

BSL **exposure** in familiar and work settings in the BSL group participants.

Questions:

How many years have you spent in a family where BSL is used?

How many years have you spent in a work environment where BSL is used?

Confidence ratings

Confidence levels of participants in language production and comprehension for BSL and for other spoken languages.

Language Attitudes

Figure 1. Summary of the most relevant features collected through the British Sign Language Profile questionnaire (Appendix 1) in our sample. Features recorded include language history (i.e. age of acquisition, years of classes, years in contexts of immersion of the language), language use (percentage of use of the language in different contexts), language proficiency (at both production and comprehension level) and language attitudes (the degree of identification with the language).

Tasks

Body-Esteem Scale

The Body-Esteem Scale (Franzoi and Shields 1984) allows exploration of emotional components related to the mental representation of the body. This scale is composed of 35 items, rating feelings about body parts (e.g. nose) and functions (e.g. appetite) on a five-point Likert scale (1= strong negative feelings, to 5= strong positive feelings).

We included this measure as emotional attitudes towards the body might well influence the use of the body itself (Longo et al. 2010). The BES can be used to ensure that participants are not performing differently on action-related tasks due to differences in these attitudes.

Hand Laterality Task

The Hand Laterality Task (HLT) requires participants to estimate if a picture of a hand refers to the right or to the left hand (Parsons 1987; 1994). We used a modified version of the HLT (Fiori et al. 2013; Fiori et al. 2014; Scarpina et al. 2019). Right back/palm and left back/palm pictures are presented at four different orientations: 0°; 90°; 180°; 270°. The task includes 16 pictures; 8 pictures of the right hand and 8 pictures of the left hand in back or palm perspective. As in other studies (Fiori et al. 2013; Fiori et al. 2014; Parsons 1987; 1994; Scarpina et al, 2019), left hands at 90° and right hands at 270° are used to obtain an index of comfortable postures, while left hands at 270° and right hands at 90° represent awkward postures.

The HLT is composed by 96 trials divided into two blocks (48 trials for each block): every stimulus is presented 6 times (3 in the first block and 3 in the second block) in a randomized order. The pictures measured 1100 by 777 pixels, covering a 1.9° by 1.3° visual angle when the images were displayed at a distance of 50cm. All stimuli were presented on a pc screen (13.3 inches, 16:9) with a resolution of 1920 by 1080 using Psycho-Py 1.83.03 (Psychology software in Pyton) (Peirce 2007).

Participants were seated in front of the pc screen, with their left and right index fingers on the keyboard, respectively over the “z” and “m” keys. They had to respond as quickly and as accurately as possible by pressing the “z” key if the picture on the screen was a left hand or by pressing the “m” key if the picture was a right hand. The response keys were reversed between blocks. The order was randomized between subjects. Every trial was preceded by a fixation cross lasting one second. For each trial, we recorded both Reaction Times (RTs) and accuracy.

Mirror Letter Discrimination Task

The Mirror Letter Discrimination Task (MLDT) has been previously developed as a control task for the HLT, using the same parameters but presenting non-body stimuli (visual imagery as opposed to motor imagery) (Fiori et al. 2013; Fiori et al. 2014; Scarpina et al. 2019). In this task, participants are required to decide if alphanumeric characters are presented in a canonical or mirror-reversed position. Stimuli are letters, "F" or "J" characters, in a canonical or mirrored-reversed perspective. All task parameters are the same as in the HLT (i.e. number of orientations, number of pictures used, number of trials, number of blocks, responses recorded).

Mental Motor Chronometry (MMC)

This task provides an explicit measure of imagery skills (Scarpina et al. 2019). Modelled after previous versions (Schwoebel and Coslett 2005; Sirigu et al. 1996), the task is composed by two conditions, an imagery condition and an execution condition. We selected the same movements as in previous studies: index and thumb opposition; thumb extension from the fist; middle finger crossed on the index finger; extension of the index and the little fingers (Schwoebel and Coslett 2005; Sirigu et al. 1996). In the imagery condition, participants imagine each movement 5 times consecutively, as quickly and as accurate as possible; in the real movement condition, subjects execute each movement 5 times as quickly and as accurately as possible. Participants were tested in both conditions with both hands. The order of movements and conditions was the same for all participants (from the index thumb opposition to the extension of the index and little fingers). The task started always with the imagery conditions (Schwoebel and Coslett 2005; Sirigu et al. 1996) in order to avoid cognitive strategies, such as counting (Sharma et al. 2009). The starting hand was counterbalanced and randomized between participants. Participants performed 8 trials in each condition as we administered the task with both hands. Subjects were seated in front of the pc screen with their left or right index finger (depending on the starting hand) on the spacebar, while the other hand lied prone on the table aligned with the subjects' shoulder line. Before starting the task, the experimenter showed each movement once, asking the subjects to repeat them once to make sure they understood the correct movement to perform. After the instructions indicating the movement to perform at the beginning of every trial, they had to close their eyes and imagine or execute the target movement five times and, when finished, press the spacebar immediately, open their eyes and move to the next trial. During the executed condition, the participants pressed the space bar with the hand not used to perform the movement. Similarly, during the imagery condition, the participants pressed the space bar with the hand not involved in the imagery task. It is worth to point out that while the hand pronation was the inter-trial starting position in the executed condition when a specific 5-times gesture trial started, the hand moved in the specific position to perform the movement, i.e., supination during index-thumb opposition, fist for the thumb extension, pronation for the middle and index fingers crossing, and prone fist for the index and little fingers extension. During the imagery condition, the hand lied prone on the table for all the task duration. Unlike in previous studies (Schwoebel and Coslett 2005; Sirigu et al. 1996), where movement times were recorded with a stopwatch, our computerized form allows more precise recording of movement times (Scarpina et al. 2019).

Mental Bar movement task

Developed as a control task for the imaginative part of the MMC, this task requires participants to imagine a movement of one or two bars, instead of fingers (Scarpina et al. 2019). There are four kinds of movements to imagine, paralleling those imagined and executed in the MMC task: two bars getting close to each other; one bar raising up from other bars; two bars crossing each other; two bars extending together from bottom to top. The order of the movements was the same for every participant as in the MMC. As for the MMC, subjects were seated in front of the pc screen with the right or left index finger on the space bar, while the other hand lied prone on the table aligned with the subjects' shoulder line.

Before starting the task, the experimenter explained each movement to imagine with the aid of static pictures. At the beginning of every trial, participants saw on the computer screen a picture representing the target movement and, after that, they closed their eyes and imagined the target movement five times. When finished, they pressed the spacebar immediately, opened their eyes and proceeded to the next movements. Each of the four movements was presented twice, in a mirrored way, to parallel the left and right-hand use in the motor imagery task.

There were 2 blocks of 8 trials: in one block participants responded with the right hand and in the other block with the left hand. The starting hand was counterbalanced and randomized between subjects.

Data analysis

Data were analysed with Statistical Package for Social Science (IBM® SPSS® Statistic, Version 25). Alpha level was set at p<.05 for all analyses.

Body-Esteem Scale

We used a one-way ANOVA in order to explore differences in the total score of the Body-Esteem Scale between groups.

Hand Laterality Task

A cut-off of 2 standard deviations above and below the individual mean was used to remove those responses indicative of anticipation and/or lack of attention respectively (Ratcliff 1993).

After data pre-processing, RTs (for accurate responses only) and average accuracy for each orientation (0°; 90°; 180°; 270°) and perspective (palm, back), for the left and right hand separately, have been calculated in each group.

To explore the effect of the stimulus orientation, we used a 2 by 3 mixed ANOVA with Group (controls, tango dancers and BSL users) as a between subjects factor and Angle of rotation (0° and 180° angle of rotation) as within subjects' factor. The same analysis has been applied to biomechanical constraints, with the within subjects' factor being postures, comfortable and awkward (90° and 270 ° angle of rotation) (Fiori et al. 2013; Parsons et al. 1995; Scarpina et al. 2019). Post hoc comparisons were carried out using estimated marginal means Bonferroni corrected for multiple comparisons, whenever necessary.

In this type of task, together with biomechanical constraints, it is useful to explore speed-accuracy trade-off. In fact, some participants may be faster but less accurate whereas others can be slower but more accurate. Combining accuracy and latencies (Bauser et al. 2011; Kiss et al. 2009) can help understanding if this is the case and discovering differences between our groups. As such we calculated the inverse efficiency score (IES) (Townsend and Ashby 1983): the average of correct RTs divided by the proportion of correct responses.

Mirror Letter Discrimination Task analysis

A cut-off of 2 standard deviations above and below the individual mean was used to remove those responses indicative of anticipation and/or lack of attention respectively (Ratcliff 1993). As for the HLT, RTs (for accurate responses only) and accuracy averages for every orientation (0°, 90°, 180°, 270°) and perspective (canonical, mirror-reversed) have been calculated after pre-processing.

We analysed two parameters that parallel those used in the HLT. The differences between 0° and 180° angles of rotation (this comparison corresponding to the stimulus orientation effect in the HLT) and between 90° and 270° angles of rotation (corresponding to the biomechanical constraints in the HLT) were entered into a 2 by 3 mixed ANOVA. Post hoc comparisons, if necessary, were carried out using estimated marginal means Bonferroni correct.

Similarly, to the HLT, we looked for speed-accuracy trade-off also in the MLD, adopting the same measure.

Mental Motor Chronometry

For each participant, first we computed the average duration of each movement for the right and the left hand separately, both in the imagery and in the motor execution conditions. From these data, we calculated the index for the imagery and motor execution, regardless of the hand. As individuals might have different movement execution times at baseline, we analysed both raw scores and the z scores transformed RTs. Raw data showed the presence of possible (not extreme, not clear cut) outliers. Due to the absence of consideration of outliers in previous studies in similar tasks (Sirigu et al, 1996; Williams et al., 2015; Zapparoli et al. 2013), we decided to not remove outliers. This is because removal of outliers might actually lead to remove effects in special populations (i.e. a person in which special expertise makes the movement and imagery slower, would end up being removed from the sample). Rather, we decided to perform a non-parametric analysis of the data as suggested by studies showing that this type of analysis is robust against effects due to outliers (Croux and Dehon 2010). This also has the benefit of allowing replicability, as anyone can adopt this approach on their data.

Hence, a Kruskal-Wallis test was performed on data, comparing the MMC index (average) between controls, tango dancers and BSL users. To check for the presence of a correlation between imagined and performed movements, in each group, separately for the right and left hand, we used Spearman's Correlation.

In case of statistically significant correlations, to directly compare the groups' strength of effects detected, we transformed the correlation coefficient values into z scores as in previous studies (Scarpina et al. 2019). This transformation is known as Fisher's r to z transformation, can be performed on the following website http://vassarstats.net/rdiff.html.

Mental Bar Movement analysis

For each participant, we computed the average duration required to imagine each movement, for the right and left side separately. The average of these two indexes was used to calculate a general index of mental imagery ability not related to the body. As well as for the MMC, we applied non-parametric analyses to prevent effects due to possible outliers.

A Kruskal-Wallis test was performed on the overall index of mental imagery to compare performance across groups. Finally, we used Spearman's Correlation to check the similarity between the imagination of the movements on the right and left side, in each group separately. As well as for the MMC, in case of statistically significant correlations we transformed the correlation coefficient values into z scores to directly compare the groups' performance for the task.

Results

Demographic Features

Gender showed a similar distribution in controls, tango dancers and BSL users (with a majority of female participants in all groups) (χ^2= 3.643; p = .162). However, groups were different in terms of education (F(2,40)= 3.585; p= .037, η^2_p= .15) and age (F(2,40)= 6.274; p= .004, η^2_p= .24). These effects were driven by a significant difference between controls and tango dancers in education (mean difference = -2.79; p = .043) and by a significant difference between controls and tango dancers in age (mean difference= -16.59; p= .003), respectively. Importantly though, as the crucial comparison is between BSL users and the other groups, there were no significant differences between BSL users and both controls and tango dancers on these variables (all ps > .05).

Nonetheless, we run all the following analyses including both education and age as covariate, when a significant Group effect was found, to ensure that any group difference is not due to confounding demographic features.

Group			**Controls**		**Tango Dancers**		**BSL users**	
			Average	*Standard Deviation*	*Average*	*Standard Deviation*	*Average*	*Standard Deviation*
BES			104.1	18	109.8	20	113.5	20
HLT-RTs	*SO*	*0*	1742.29	560.25	1939.64	635.30	1553.42	505.03
		180	2374.61	1151.05	3292.54	1459.15	2427.83	908.52
	BC	*C*	1844.71	670.37	2081.36	756.64	1763.60	662.51
		A	2158.52	909.26	2832.25	1416.79	2150.89	1011.41
HLT-Accuracy	*SO*	*0*	89.29	8.45	94.85	5.42	96.18	4.15
		180	76.49	18.53	81.62	19.27	83.68	11.16
	BC	*C*	86.31	11.37	94.85	5.21	96.18	3.75
		A	84.23	12.57	94.36	5.88	88.54	11.67
MLD-RTs	*0*		1181.18	208.14	1317.71	327.33	1057.45	115.81
	90		1429.74	276.30	1484.31	357.41	1337.51	295.90
	180		1750.64	361.74	1992.01	663.67	1865.41	545.55
	270		1457.62	292.44	1521.67	417.03	1306.92	245.71
MLD-Accuracy	*0*		95.24	5.13	97.79	3.33	95.14	3.91
	90		91.37	12.06	91.67	12.33	92.01	11.02
	180		83.33	13.87	83.58	18.31	79.51	22.44
	270		94.05	4.82	91.91	12.01	92.36	10.93
MMC	*MI*	*Left Hand*	6162.56	2071.11	7218.55	3962.45	6001.91	3185.25
		Right Hand	6013.08	1961.20	6377.52	3401.34	5044.95	1598.13
	ME	*Left Hand*	5607.05	1621.66	4787.90	2464.05	4490.12	1624.99
		Right Hand	5664.89	1818.97	4882.12	2162.07	4356.54	1515.62
MBM	*Left*		6766.90	2511.46	7832.36	3874.75	7095.27	3478.55
	Right		6675.64	2294.36	7339.76	3064.07	7110.36	3602.41

Table 1. Average and standard deviation for all tasks results. Reaction times (ms) and accuracy (percentage of correct answers). BES = Body Esteem Scale. HLT = Hand Laterality Task. SO = Stimulus Orientation. BC = biomechanical constraints. C = comfortable postures. A = awkward postures. 0, 90, 180 and 270 = degrees of rotation. MLD = Mirror Letter Discrimination Task. MMC = Mental Motor Chronometry. MI = Motor Imagery. ME = Motor Execution. MBM = Mental Bar Movement.

Body-Esteem Scale (Table 1)

We did not find any significant difference across groups on the global index of the BES (F(2,40)= .802; p= .456, η^2_p = .04). Controls had an average score of 104.1 (SD 18), tango dancers of 109.8 (SD 20) and BSL users of 113.5 (SD 17). We did not include the BES in further analysis as there is no rationale to assume that any difference might be driven by attitudes, or more emotional components, towards the body itself.

Hand Laterality Task

Effect of Stimulus orientation *(Table 1)*

We found a significant effect of Stimulus Orientation in RTs (F(1,40) = 58.210, p<.001, η^2_p = .59), while Group main effect was not significant (F(2,40) = 2.375, p= .106, η^2_p = .11). We did not find any significant interaction between Group and Stimulus Orientation (F(2,40) = 3.185, p= .052, η^2_p = .14). As expected, participants had faster RTs with stimuli at 0° (Mean= 1767.60; ± SD= 585.67) than with those at 180° (Mean= 2752.37; ± SD= 1277.94) independently from the group they belonged to.

Similarly to RTs, we found a significant main effect of Stimulus orientation (F(1,40) = 26.992, p<.001, η^2_p = .40) when considering accuracies; participants were significantly more accurate with stimuli at 0° (Mean= 93.41; ± SD= 6.82) than those at 180° (Mean= 80.52; ± SD= 17.00). We did not find any main effect of Group (F(2,40) = 1.782, p= .181, η^2_p = .08) nor any interaction between Group and Stimulus Orientation (F(2,40) = .008, p= .992, η^2_p < .001).

Our results indicate a stable effect of stimulus orientation in accuracy and RTs, which is not related to how individuals use their body.

When analysing the data using the combined IES score, our results showed the same tendency, where only the effect of Stimulus Orientation (F(1,40) = 33.211, p<.001, η^2_p = .45) is significant. Group (F(2,40) = 1.764, p= .184, η^2_p = .08) as well as the interaction between Group and Stimulus Orientation ($F(2,40) = 1.245$, $p = .299$, $\eta^2_p = .06$) did not reveal any significant effect.

Effect of Biomechanical constraints *(Table 1)*

Participants showed significantly faster RTs for hands in comfortable postures (Mean= 1915.63; ± SD= 701.10) and slower RTs for hands in awkward postures (Mean= 2422.75; ± SD= 1183.54) (Main effect of Biomechanical Constraints, $F(1,40) = 18.036$, $p<.001$, $\eta^2_p = .31$), confirming the presence of biomechanical constraints. Importantly, the main effect of Group was not significant ($F(2,40) = 1.485$, $p = .239$, $\eta^2_p = .07$), as well as the interaction between Group and Biomechanical Constraints ($F(2,40) = 1.558$, $p = .223$, $\eta^2_p = .07$).

For accuracy, there was a significant effect of Biomechanical Constraints ($F(1,40) = 5.892$, $p = .020$, $\eta^2_p = .13$), with a more accurate performance for comfortable posture (Mean= 92.44; ± SD= 8.54) than awkward postures (Mean= 89.44; ± SD= 10.81) (Figure 2 panel A). The interaction between Group and Biomechanical Constraints was not significant ($F(2,40) = 2.275$, $p = .116$, $\eta^2_p = .10$).

Group showed a significant main effect too ($F(2,40) = 5.961$, $p = .005$, $\eta^2_p = .23$); post-hoc comparisons revealed that this is driven by a significant difference between tango dancers (Mean = 94.61; SE = 1.86), more accurate, and controls (Mean=85.27; SE = 2.05), less accurate (mean difference = 9.34; p= .005) (Figure 2 panel B). To ensure this is not due to age differences (given tango dancers are older than controls) or educational differences (which might be related to differences also in understanding instructions), we run the same analysis with each of these variables separately as covariate. When introducing age in the model, Group is still significant ($F(2,39) = 3.858$, $p = .030$, $\eta^2_p = .16$), with tango dancers being more accurate than controls (mean difference = 8.62; p= .031). As for education, the same pattern emerges

(F(2,39) = 5.545, p= .008, η^2_p = .22) with the same directionality (mean difference = 9.73; p=.008).

Combining accuracy and reaction times to ensure, the effect of Biomechanical Constraints (F(1,40) = 21.368, p<.001, η^2_p = .35) remains significant, and the findings for the interaction between Group and Biomechanical Constraints are confirmed (F(2,40) = .679, p= .513, η^2_p = .03). However, the main effect of Group is not significant anymore (F(2,40) = .580, p= .565, η^2_p = .03),

Overall data on biomechanical constraints show a difference between tango dancers and controls, with the former being more accurate but not faster. Our IES analysis further explain this result, suggesting that the greater accuracy in tango dancers is reached at the expenses of providing a fast response. On the other hand, using hands for linguistic purposes does not affect how people imagine their hands.

One could question if our null effects in the Hand Laterality Task are due to a lack of power. We run a posteriori power analysis to ensure that the results in this task, core to our hypothesis, are not due to lack of power. In the Mental Chronometry task, the correlations are significant, hence the concern for null effects does not apply. We used G-Power to obtain an estimate of the observed power in the Hand Laterality Task. We looked at the effects of Group and Interactions for this factor. This analysis revealed that power achieved was between .88 and .99 for the HLT (RTS: using Group parameters: power .88; using interaction Group and Biomechanical Constraints parameters: power .88; accuracy: using interaction Group parameters: power .99, using interaction Group and Biomechanical Constraints parameters: power .97), suggesting that the null effect is unlikely to be due to lack of power.

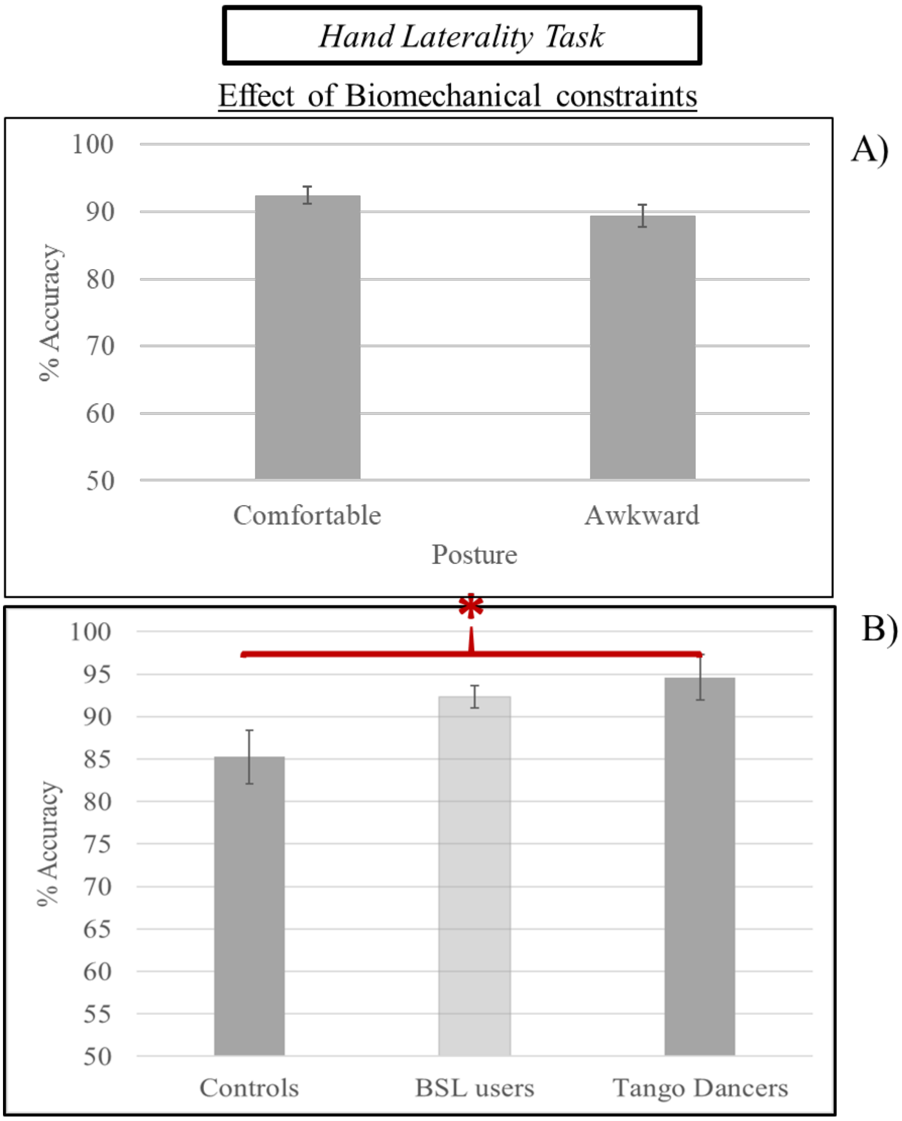


Figure 2. Accuracy data for the HLT, biomechanical effects. A) The significant main effect of Biomechanical Constraints. Awkward postures generate less accurate responses than comfortable ones. B) The interaction between Posture and Group is driven by the significant difference between tango dancers (more accurate) and controls. BSL users' performance is depicted as a fading bar to highlight that their performance is not different from the other groups. Bars represent standard error of the mean. The red line and asterisk represent the significant difference between tango dancers and controls. The y-axis represents the percentage of correct answers.

Mirror Letter Discrimination Task (Table 1)

0° versus 180°

Participants had faster RTs with stimuli at 0° (Mean= 1200.63; ± SD= 263.19) than those at 180° (Mean= 1878.09; ± SD= 544.94) (F(1,40) = 96.400, p< .001, η^2_p = .71). Group was not significant (F(2,40) = 1.449, p= .247, η^2_p = .07) and we did not find any significant interaction between Group and Angles of rotation (F(2,40) = .900, p= .415, η^2_p = .04).

Taking into account accuracy, there was a significant main effect of Angles of rotation (F(1,40) = 26.179, p< .001, η^2_p = .40), while Group was not significant (F(2,40) = .404, p= .670, η^2_p = .02). In particular, participants were more accurate with stimuli at 0° (Mean= 96.22; ± SD= 4.25) than those at 180° (Mean= 82.36; ± SD= 17.95). As for RTs, no significant interactions were found (F(2,40) = .149, p= .862, η^2_p = .01).

Our data analysed considering the combined IES score, participants are still more efficient with stimuli at 0° (F(1,40) = 38.273, p< .001, η^2_p = .49). Group (F(2,40) = .555, p= .578, η^2_p = .03) and the interaction between Group and Angles of rotation (F(2,40) = 1.287, p= .287, η^2_p = .06) remains not significant.

90° versus 270°

RTs for Angle of rotation (F(1,40) = .116, p=735, η^2_p = .003), Group (F(2,40) = 1.224, p= .305, η^2_p = .06) and the interaction between Group and Angles of rotation (F(2,40) = .369, p= .694, η^2_p = .02) were all not significant. Similarly, accuracy did not show significant effects for Angle of rotation (F(1,40) = .659, p= .422, η^2_p = .016), Group (F(2,40) = .032, p= .968, η^2_p = .002) or interactions between factors (F(2,40) = .356, p= .703, η^2_p = .02). IES scores confirm this pattern: no main effects (Angle of rotation (F(1,40) = .175, p= .678, η^2_p = .004); Group (F(2,40) = .787, p= .462, η^2_p = .04)), and no interaction between main effects become significant (F(2,40) = .318, p= .730, η^2_p = .02).

Our results overall show that any difference emerging in motor imagery is not due to basic differences in visual imagery.

Mental Motor Chronometry (Table 1)

Analysis of the raw RTs did not reveal any significant difference between groups ($\chi^2(2)$ = 1.087, p = 0.581). When running the same analyses using Z-transformed scores, to control for baseline differences, we confirmed the absence of differences among groups ($\chi^2(2)$ = 1.347, p = 0.510).

As transformed and raw scores provide the same pattern of results, we used raw scores for the next analyses to explore the correlation between Motor Imagery (MI) and Motor Execution (ME). We found a significant positive correlation in the control group for both the right (p(12) = . 534; p = .049; two-tails) and left hand (p(12) = . 701; p = .005; two-tails) (Figure 3). Similarly, in the tango dancers, we were able to see the classic correlation between imagining and executing a movement for both the right (p(15) = . 669; p = .003; two-tails) and the left hand (p(15) = . 620; p = .008; two-tails) (Figure 3). BSL users showed the significant positive correlation between MI and ME condition in both hands too, right (p(10) = . 608; p = .036; two-tails) and left (p(10) = . 650; p = .022; two-tails) (Figure 3).

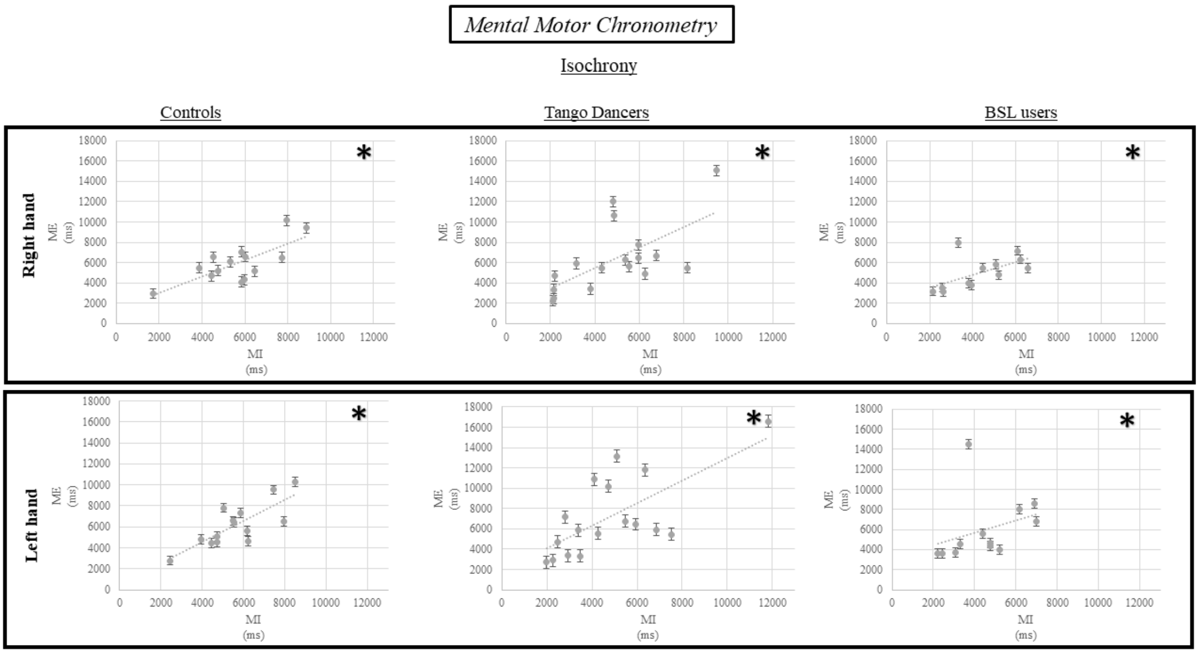


Figure 3. Isochrony (correlation between execution and imagery) for the MMC task. Top row: data for the left hand. Bottom row: data for the right hand. Asterisk indicates significant correlations. Bars represent standard error of the data in each group.

Fisher's analysis was conducted for both the right and the left hand in all groups, to explore group differences in terms of strength of the effect found (Scarpina et al. 2019). The comparison between BSL users and tango dancers [z = -0.24; p = 0.810], between BSL users and controls [z = 0.24; p = 0.810] and between controls and tango dancers [z = -0.53; p = 0.596] did not reveal any significant difference, confirming that the MMC pattern of results is comparable in spite of the different special manual expertise. The same reasoning applies to left hand, where the comparison did not reveal differences in the strength of the correlation among groups (BSL users VS tango dancers [z = 0.12; p = 0.904]; BSL users and controls [z = -0.21; p = 0.833]; controls and tango dancers [z = 0.36; p = 0.718]).

Mental Bar Movement (Table 1)

Performance in the MBM was not different among groups ($\chi^2(2) = .538$, p = 0.764). Controls showed a significant positive correlation between movements imagined on the right and left side of space ($p(12) = .908$; $p < .001$; two-tails), as well as tango dancers ($p(15) = .956$; $p < .001$; two-tails), and BSL users ($p(10) = .958$; $p < .001$; two-tails).

Similarly to the MMC and the approach in previous studies (Scarpina et al. 2019), we checked for group differences using the Fisher's r to z transformation. The comparison between BSL users and tango dancers [z = 0.06; p = 0.952], between BSL users and controls [z = 0.9; p = 0.368] and between controls and tango dancers [z = -0.95; p = 0.342] did not reveal any significant difference between groups, suggesting that special expertise does not affect the visual imagery skills required to solve this task.

Discussion

Since the publication of the first Sign Language (SL) dictionary in America (Stokoe et al. 1965), researchers have established SLs as syntactically complex languages with distinctive morphological, phonological, and sociolinguistic features, which are distinct from spoken languages, have no vocal element and are constituent of vibrant cultures (Pfau et al. 2012). The British Deaf community consists of Deaf and hearing British Sign Language (BSL) users (Salzmann et al. 2000). The British Deaf Association estimates 87,000 BSL users who are deaf and 151,000 BSL users in total when hearing people are included (British Deaf Association, 2020: https://bda.org.uk/help-resources/). In spite of the dimensions of Deaf communities and the relevance of the issue (e.g. as a fundamental prelude to ensuring access to interpreters in health, justice and educational settings: see Harrington and Turner 2001), it is still unknown what attributes are important to become a fluent signer.

SLs users have hand dominance in relation to language (Vaid et al. 1989), refer to proprioception to a greater extent for communication purposes (Emmorey et al. 2007), and use their peripersonal space (i.e. the space within reaching distance) as a linguistic space (Chatterjee 2001). In summary, the creation, production, and modification of signs in SLs are clearly rooted not only in general visuo-spatial skills but also in the body and how it is used in space, hence to body representation (de Vignemont 2010; Holmes and Spence 2004). Evidence from visual imagery and face discrimination shows that non-linguistic spatial cognition is enhanced in SLs (Emmorey et al. 1993), but as we know these representations do not necessarily predict the ability to imagine our own body (Gentilucci et al. 1998a, 1998b; Parsons 1987; 1994; Sekiyama 1982).

In our study, we explored the ability to represent the body in relation to action in BSL users, by means of classic tasks that allow establishing how much the physical constraints of the body impact on how we represent it. We focused on motor imagery, the representation of the body in relation to actions.

Importantly, we compared the performance of BSL users to that of not only controls but also tango dancers. Professional dancers, in fact, have been described as having a higher proprioceptive ability, a skill that is the direct consequence of how they use their body (Jola et al. 2011; Ramsay and Riddoch 2001). By using tasks that require explicitly thinking about one own' s body and tasks in which the use of motor imagery is less explicit, we also aimed at establishing if any difference detected is related to the level of awareness that one has when imagining movements (Scarpina et al. 2019).

Our results are clear-cut in pointing out that there are no differences in representing the physical body when people use it to communicate in BSL. Mainly, the use of the body as a mean of communication by BSL users does not affect how the individuals solve the more implicit task (requiring less awareness) that we presented here. Similarly, even when we require explicit knowledge to solve a task, the linguistic function of the body does not impact (i.e. slower decisions, less accuracy) on our mental representation. BSL users perform similarly to the other groups, both in terms of how fast the task was solved and in terms of how accurately it was performed. Secondly, feelings towards the body, as measured here with a general body esteem scale, also do not seem to play a role. We did not find any difference between the groups, suggesting that the individuals who took part in our study do not have specific concerns about their physical appearance.

We did find a difference between tango dancers' performance and that of controls: tango dancers are more accurate in their judgements compared to controls, in the more implicit task requiring them to mentally rotate hands. With this result, we expand what is known about dancers. Dancers, even when not professionals, exhibit a superior perception at single joints level (Kuni and Schmitt 2004; Ramsay and Riddoch 2001), greater proprioceptive acuity if compared to non-dancers (Ramsay and Riddoch 2001) and proprioceptive awareness (Kiefer et al. 2013) and a more coherent representation of their body (Jola et al. 2011; Miura et al. 2011). Here, we show also more accurate motor imagery skills when the task can be solved implicitly. It should be noted that this difference observed in dancers is due to a speed-accuracy trade-off: the greater accuracy in tango dancers is reached at the expenses of providing a fast response. It might be that the above-mentioned abilities, such as greater proprioceptive acuity and awareness, lead to a change in the strategy that tango dancers use to solve the task. Tango dancers could rely on a less implicit strategy as they are more aware of their bodies and hence be more accurate.

One interesting component that could be taken into account to explain our pattern of results is that while using the body to communicate might require more awareness and conscious access to a representation, dancing tango can instead be a more automatic process. On the other hand, one could argue that it is the time spent using the body for dancing that explains our findings.

The tango dancers we recruited were dancing for 7.6 years on average (SD 6) and on average 4.2 hours a week (SD 2). On the other hand, BSL users involved in the study spent on average 4.1 years (SD 9) in a family using BSL and 2 years (SD 2) in a work environment using BSL. For tango dancers, we can use the precise number of years and number of hours practiced in a week to test this hypothesis. We looked at accuracy data where a group effect was found and that we firstly explained in terms of expertise. Neither hands in comfortable positions ($p(17) = -.248$; $p = .337$, two-tails) nor hands in awkward positions data ($p(17) = -.073$; $p = .781$, two-tails) showed a significant correlation with years of expertise. As such, it is unlikely that expertise levels can explain our results, and the different strategy as suggested above remains a more likely candidate.

Our results could nonetheless be interpreted in the light of the status of the BSL users as relatively recent adult learners of the language: in other words, they have not been using their bodies for these linguistic purposes for many years. It could be that the time required to "change" the representation of the body in action is longer and hence we were not able to see differences. Given the nature of our data on BSL users we cannot run the same correlations to establish a role for expertise. As can be seen from our figure 1, 67% (8/12) of our BSL participants learned the language at 20+ years, making the sample unsuitable for such an analysis. Nonetheless, we can reason in terms of plausibility of this hypothesis. In case of impairments, i.e. with patients with injuries to the spinal cord (Fiori et al. 2013; Fiori et al., 2014; Sedda et al. 2019), changes appear almost immediately, at months from the lesion. Similarly, it has been shown that in healthy individuals the use of a wheelchair immediately modifies our ability to represent action-related properties of the body (Galli et al. 2015). Hence, the idea of having to accumulate a certain amount of expertise to have a change in how we represent the body in relation to BSL does not seem to be supported by the available evidence. Another possible explanation is that using group averages in the case of such complex variables as the influence of experience but also its type on BSL learning and use might not be the right approach. In this case, single cases descriptions could be a better approach. Further studies testing these BR abilities in users since a very early aged and fully immersed in a BSL environment for most of the time, versus a sample of late learners, could clarify the role of experience.

In the task exploring the component more related to an explicit awareness of our "mental" body, BSL users do show the classic isochrony between imagining and moving for their left hand. This is of particular interest given that our participants indicated that their preferred hand for signing is their right one. The left hand becomes for them a signpost rather than an active agent in a lot of gestures (Vaid et al. 1989). The non-dominant hand has a specific role as a "manual tab" in sign linguistics. It acts as a base upon which the other hand acts (Salzmann et al. 2000). However, this does not impact on action related uses of the hand. Different functions coexist, without any loss in terms of brain representation.

In summary, our study shows that using the body for different purposes (i.e. different types of body expertise) not necessarily lead to changes in motor imagery skills and constraints.

Whether mental representation of the body in action in BSL users can explain proficiency in the use of this language is worth exploring further. Mostly our participants are relatively early-stage learners – they cannot be described as "proficient" signers yet, their performance is not by any means necessarily predictive of that of more skilled, fluent, long-term users. Given also previous knowledge on visual imagery skills in Deaf individuals, it is also worth exploring if the pattern we have identified in hearing BSL users is replicated in individuals who are "born into BSL". In the case of Deaf individuals, the pervasive effect of BSL use could even be greater. However, it could also be the case that the distinction between more and less explicit, more and less aware processes, still holds. Importantly, given the cultural dimension of BSL, future studied should consider moving towards exploring body ownership and more aspects of body representation related to the self (Longo et al. 2009).

Acknowledgements

The Authors are thankful to the participants of this study and their willingness to share with us their time.

Conflict of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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