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## BODILY RELATIVITY

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### Introduction

Our bodies are an ever-present part of the context in which we use our minds. Thinking depends on context. Therefore, our bodies could exert myriad influences on how and what we think. How can we identify ways in which our bodily interactions with the environment are shaping our brains and minds? One strategy is to investigate whether people with different kinds of bodies think differently, in predictable ways. This chapter reviews research exploring ways in which the particulars of people's bodies shape their words, thoughts, feelings, and choices, and ways in which our habits of body-world interaction determine how thoughts and feelings are implemented in our brains.

This research is motivated by the *body-specificity hypothesis* (Casasanto, 2009, 2011): to the extent that the content of the mind depends on our interactions with our environment, people with different kinds of bodies – who interact with the environment in systematically different ways – should tend to form correspondingly different neural and cognitive representations. The body-specificity hypothesis has now been validated by more than two dozen experiments, conducted in a variety of populations on four continents, using methods that range from questionnaires (e.g. Casasanto, 2009) and reaction time tasks (e.g. de la Vega, de Filippis, Lachmair, Dudschig, and Kaup, 2012) to analyses of spontaneous gesture (Casasanto and Jasmin, 2010), memory tasks (Brunyé, Gardony, Mahoney, and Taylor, 2012), lesion-outcome studies (e.g. Casasanto and Chrysikou, 2011), visual hemifield (VHF) manipulations (Brookshire and Casasanto, 2013), functional magnetic resonance imaging (fMRI; e.g. Willems, Hagoort, and Casasanto, 2010), electroencephalography (EEG; Brookshire and Casasanto, 2012), and transcranial direct current stimulation (tDCS; Brookshire, Graver, and Casasanto, 2013). The mental processes and cognitive domains that exhibit body specificity include action verb understanding (Willems *et al.*, 2010), idiom comprehension (de la Vega, Dudschig, Lachmair, and Kaup, in press), motor imagery (Willems, Toni, Hagoort, and Casasanto, 2009), emotional valence (e.g. Casasanto, 2009), and affective motivation (Brookshire and Casasanto, 2012).

In light of the amount and diversity of the data, these studies that support the body-specificity hypothesis can be considered to be the first wave of evidence for a theory of *bodily relativity* (Casasanto, 2011), which can be described by analogy to a theory of linguistic relativity. Language and the body are two particularly stable and omnipresent aspects of the context in which

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we do our thinking, both of which act as crucial points of interface between the mind and the world, and thereby shape the way we think. Just as speakers of different languages come to think differently in various ways, via a variety of mechanisms (Boroditsky, 2011; Casasanto, 2012; Lupyan, 2012), so do people with different kinds of bodies think differently, in various ways, via a variety of mechanisms that can have subtle or dramatic effects on brain and behavior.

### **Body specificity of action language and motor imagery**

Initial tests of the body-specificity hypothesis used handedness as a “fruit fly”: a simple model system for testing broad principles. Unlike actual fruit flies, the hands are indispensable in our daily lives, mediating countless interactions between people and their environment – and importantly, different people use their hands differently, in some ways that are easy to observe and quantify.

Right- and left-handers often perform the same actions differently. When people throw a ball, sign a check, or grasp a coffee mug they usually use their dominant hand. Do differences in how people perform actions influence the way they imagine actions and process action language? To find out, my collaborators and I used fMRI to compare right- and left-handers’ brain activity during motor imagery and action verb understanding.

### *Imagined actions*

In one experiment, participants were asked to imagine performing actions while lying perfectly still in the fMRI scanner. They imagined some actions that are usually performed with the dominant hand (scribble, toss) and some actions performed with other parts of the body (kneel, giggle). Mental imagery for hand actions corresponded to different patterns of activity in right- and left-handers’ motor systems. Left-hemisphere motor areas were activated in right-handers, but right-hemisphere motor areas were activated in left-handers (Willems *et al.* 2009). People with different kinds of bodies imagine the same actions differently, in this case using opposite hemispheres of the brain.

### *Motor action and verb meaning*

A similar pattern was found when people read words for actions they usually perform with their dominant hands or with other parts of the body. When right-handers read words for hand actions they preferentially activated the left premotor cortex, an area used in planning actions with the right hand. Left-handers showed the opposite pattern, activating right-hemisphere premotor areas used for planning left-hand actions (Willems *et al.*, 2010). This was true even though they were not asked to imagine performing the actions, or to think about the meanings of the verbs. Further fMRI experiments confirmed that activation during action verb reading was not due to conscious imagery of actions (Willems, Toni, Hagoort, and Casasanto, 2010).

Do the *meanings* of action verbs differ between right- and left-handers? One way to address this question is to determine whether the motor areas that show body-specific patterns of activation play a functional role in verb processing. We used theta-burst repetitive transcranial magnetic stimulation (rTMS) to modulate neural activity in the premotor hand areas identified in our earlier fMRI study. Participants’ ability to distinguish meaningful manual action verbs from pseudo-words was affected by rTMS to the premotor cortex in the hemisphere that controls their dominant hand, but not in the other hemisphere. The rTMS to the hand areas had no effect on processing non-manual action verbs, which served as a control. These data

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suggest that, when people read words like *grasp*, neural activity in the premotor area that controls the dominant hand is not an epiphenomenon, or a downstream consequence of semantic processing. Rather, body-specific activation of the motor system plays a functional role in processing language about hand actions (Willems, Labruna, D'Esposito, Ivry, and Casasanto, 2011). People tend to understand verbs as referring to actions they would perform with their particular bodies – not to a Platonic ideal of the action, or to the action as it is performed by the majority of language users. In this sense, people with different bodies understand the same verbs to mean something different.

These results are also informative about the kind of experience that people simulate when understanding action verbs: seeing actions or performing actions. Following Pulvermüller (Pulvermüller, 2005), numerous studies have shown effector-specific activity cued by action verbs: hand areas respond selectively to hand-related verbs, foot areas to foot-related verbs, etc. Based on previous studies, however, it was not clear to what extent the motor component of action word meanings reflects actions we have observed others performing with their bodies (*allocentric simulation*) or actions we have performed ourselves (*egocentric simulation*). The allocentric possibility predicts that neurocognitive representations of manual action word meanings should be similar in right- and left-handers, since presumably everyone observes about the same proportion of right- and left-handed actions by other people. The discovery that motor activity associated with manual action words is body specific supports the egocentric possibility and suggests that, at least by default, people implicitly simulate their own prior or potential actions when understanding action words.

### Body specificity of emotion

Abstract concepts of things we can never perceive with the senses or act upon with the muscles are the hard case for any theory that foregrounds the role of bodily experience in constructing the mind. Beyond the concrete domain of action, how might bodily experience shape mental representations of more abstract ideas like *goodness* and *badness*, *victory* and *loss*, *deceit* and *honesty*? Like many abstract concepts, these notions carry either positive or negative emotional valence. Affective valence (i.e. positivity or negativity) and motivation (i.e. the predisposition to approach or withdraw from physical and social situations) appear to be grounded in patterns of body-specific motor experience.

### Emotional valence: choosing sides

Across languages and cultures, good things are often associated with the right side of space and bad things with the left. This association is evident in positive and negative idioms like *my right-hand man* and *two left feet*, and in the meanings of English words derived from the Latin for “right” (*dexter*) and “left” (*sinister*).

Beyond language, people also conceptualize good and bad in terms of left-right space, but not always in the way linguistic and cultural conventions suggest. Rather, people's implicit associations between space and valence are body specific. When asked to decide which of two products to buy, which of two job applicants to hire, or which of two alien creatures looks more trustworthy, right- and left-handers respond differently. Right-handers tend to prefer the product, person, or creature presented on their right side but left-handers tend to prefer the one on their left (Casasanto, 2009). This pattern persists even when people make judgments orally, without using their hands to respond. Children as young as five years old already make evaluations according to handedness and spatial location, judging animals shown on their dominant

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side to be nicer and smarter than animals on their non-dominant side (Casasanto and Henetz, 2012).

The implicit association between valence and left-right space influences people's memory and their motor responses, as well as their judgments. In one experiment, participants were shown the locations of fictitious positive and negative events on a map, and asked to recall the locations later. Memory errors were predicted by the valence of the event and the handedness of the participant: right-handers were biased to locate positive events too far to the right and negative events too far to the left on the map, whereas left-handers showed the opposite biases (Brunyé *et al.*, 2012). In reaction time tasks, right- and left-handers were faster to classify words as positive when responding by pressing a button with their dominant hand, and faster to classify words as negative when responding with their non-dominant hand (de la Vega *et al.*, 2012).

Left-handers have no choice but to use verbal idioms that suggest the right side is the good side: lefties cannot use *two left feet* to mean graceful, or refer to the correct answer as *the left answer*. Yet, one experiment suggests that left-handers process these idioms differently than right-handers. Left-handers responded slower than right-handers when asked to judge highly conventional good-is-right and bad-is-left idioms, but there was no difference between groups when participants judged literal left-right expressions or handedness-irrelevant metaphors (de la Vega *et al.*, in press).

Beyond the laboratory, the association of "good" with the dominant side can be seen in left- and right-handers' spontaneous speech and gestures. In the final debates of the 2004 and 2008 US presidential elections, positive speech was more strongly associated with right-hand gestures and negative speech with left-hand gestures in the two right-handed candidates (Bush, Kerry), but the opposite association was found in the two left-handed candidates (McCain, Obama; Casasanto and Jasmin, 2010). Body-specific associations between space and valence have visible consequences for the way people communicate about positive and negative ideas.

### *How using your hands can change your mind*

Why do right- and left-handers think differently in this way? These results cannot be predicted or explained by conventions in language and culture, which consistently associate "good" with "right" and "bad" with "left." Instead, implicit associations linking valence with left-right space appear to be created as people interact with their physical environment. In general, greater motor fluency leads to more positive feelings and evaluations: people like things better when they are easier to perceive and interact with (e.g. Ping, Dhillon, and Beilock, 2009). Bodies are lopsided. Most of us have a dominant side and a non-dominant side, and therefore interact with the physical environment more fluently on one side of space than on the other. As a consequence right-handers, who interact with their environment more fluently on the right and more clumsily on the left, come to implicitly associate "good" with "right" and "bad" with "left," whereas left-handers form the opposite association (Casasanto, 2009).

To test this proposal, Evangelia Chrysikou and I studied how people think about "good" and "bad" after their dominant hand has been handicapped, either due to brain injury or to something much less extreme: wearing a bulky ski glove. One experiment tested space-valence mappings in stroke patients with hemiparesis (weakness or paralysis) on either their right or left side following damage to the opposite hemisphere of the brain. The patients, who had all been right-handed prior to brain injury, performed a task known to reveal body-specific space-valence associations in healthy participants. Patients who lost the use of their left hand post-stroke showed the usual right-is-good pattern. By contrast, patients who had lost the use of their right hand associated "good" with "left," like natural left-handers.

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A similar reversal was found in healthy university students who performed a motor fluency task while wearing a cumbersome glove on either their left hand (which preserved their natural right-handedness), or on their right hand, which turned them temporarily into left-handers. After about twelve minutes of lopsided motor experience, participants removed the glove and performed a test of space-valence associations, which they believed to be unrelated. Participants who had worn the left glove still thought “right” was “good,” but participants who had worn the right glove showed the opposite left-is-good bias, like natural lefties (Casasanto and Chrysikou, 2011).

Motor experience plays a causal role in shaping abstract thoughts. Even a few minutes of acting more fluently with the left hand can change right-handers’ implicit associations between space and emotional valence, causing a reversal of their usual judgments. People generally have the impression that their judgments are rational and their concepts are stable. But if wearing a glove for a few minutes can reverse our usual decisions about what is good and bad, the mind may be more malleable than we thought.

The effects of short-term motor asymmetries are presumably temporary, but the same associative learning mechanisms that changed people’s judgments in the laboratory training task may result in the long-term changes we found in stroke patients, and may shape natural right- and left-handers’ space-valence associations in the course of ordinary motor experience. Using our asymmetrical bodies, and therefore interacting with the physical environment more fluently on one side of space than the other, may serve as a kind of natural “motor training.”

### *Is valence differently lateralized in right- and left-handers’ brains?*

The discovery of body-specific associations between space and valence motivates a re-evaluation of an influential model of emotional valence in the brain, according to which the left hemisphere is specialized for positive emotions and the right-hemisphere for negative emotions (e.g. Davidson and Sutton, 1995). Dozens of studies have used lateralized stimulus or response tasks to investigate the hemispheric correlates of valence, most typically VHF manipulations in which positive and negative stimuli (e.g. happy/sad faces) were presented briefly to the right or left of a central fixation point, to send visual information to the contralateral hemisphere. Studies manipulating the right vs. left VHF have been interpreted as showing that positive emotions are processed in the left hemisphere and negative emotions in the right hemisphere (e.g. Reuter-Lorenz and Davidson, 1981). At least this appears to be the case in right-handers. Over the past three decades, there have been occasional reports of deviations from this well-established pattern when VHF-emotion studies have been conducted in left-handers (e.g. Everhart, Harrison, Crews, 1996; Natale, Gur, and Gur, 1983). The left-handers’ data have been somewhat inconsistent, and have been largely interpreted as noise, but they raise the possibility that hemispheric specialization for valence could vary with handedness. An alternative possibility, however, is that only *responses* in VHF-emotion studies could vary with handedness.

Although the goal of these VHF studies has been to determine hemispheric organization of emotion, there are reasons to reconsider whether they can be interpreted with respect to that goal – and whether valence is differently lateralized in right- and left-handers’ brains (or, indeed, lateralized at all). Body-specific space-valence associations provide an alternative explanation for *all* previous VHF-emotion experiments, and for related experiments using lateralized auditory or haptic presentation of emotional stimuli (e.g. McFarland and Kennison, 1989) or lateralized manual outputs (e.g. Kong, 2013; Root, Wong, and Kinsbourne, 2006). Stimuli presented to the right VHF appear on the participant’s right side of space; stimuli presented to the left VHF appear on the participant’s left side. Therefore, presenting positive and negative stimuli on a

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participant's "good" and "bad" side could produce "VHF effects" even if participants were not selectively processing the stimuli in one hemisphere or the other. Many of the space-valence experiments reviewed above show that laterally presented stimuli can activate space-valence associations even when the stimuli are processed slowly and presumably *bi-hemispherically*. Therefore, there is no need to posit hemispheric specialization for emotion to account for emotional VHF effects.

In short, in light of what we have learned in this program of research so far, it appears that decades of emotional VHF experiments may have been drastically misinterpreted. If emotional VHF effects are, in fact, due to body-specific associations in memory, created by habitual asymmetries in manual motor fluency, then two predictions follow. First, right- and left-handers should show opposite patterns of responses on an emotional VHF task. Second, response patterns should *reverse* with motor training that temporarily reverses hand dominance (as in Casasanto and Chrysikou, 2011).

A test of this proposal supported both of these predictions. First, in a version of a classic VHF experiment on emotional face judgments, right-handers were more likely to judge neutral faces to be positive when they appeared on the right of fixation and to be negative when they appeared on the left – but left-handers showed the opposite pattern (Brookshire and Casasanto, 2013). The strength of the body-specific judgment bias varied parametrically with the participant's degree of handedness, as measured by participants' scores on the Edinburgh Handedness Inventory (EHI; Oldfield, 1971). Right- and left-handers showed opposite emotional VHF effects.

In a second experiment, right-handers performed the ski-glove training task (Casasanto and Chrysikou, 2011) before the VHF face task. After training, participants who had worn the glove on their right hand (becoming transiently left-handed in the relevant regard) were more likely to judge neutral faces to be positive when they appeared on their left of fixation and to be negative when they appeared on the right – like natural left-handers. Twelve minutes of motor experience can completely reverse the emotional VHF effect typically found in right-handers (in our study and in many others like it). It is more likely that this twelve-minute training intervention was able to alter fluency-based associations between space and valence in participants' memory than to completely reverse any gross hemispheric specialization for valence.

### *Summary of body-specific space-valence associations*

Right- and left-handers form the opposite implicit associations between left-right space and positive and negative emotional valence. Each group tends to associate "good" with their dominant side of space and "bad" with their non-dominant side. For right-handers, these associations accord with linguistic and cultural conventions that link "good" with "right," but left-handers' implicit associations contradict these conventions. These implicit associations appear to be formed as people interact with their environment more fluently on their dominant side of space and more clumsily in their non-dominant side, as evidenced by stroke patients and laboratory participants who have their naturally dominant hand impaired (permanently or transiently) and show a corresponding reversal of their space-valence association.

This discovery suggests that numerous behavioral studies previously interpreted as evidence for hemispheric specialization of positive and negative valence should be reinterpreted. The results VHF-emotion tasks (and other lateralized stimulus and response tasks) can be explained in terms of previously undocumented mnemonic associations between space and valence. These data do not require an explanation in terms of hemispheric specialization, which seems very

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unlikely to be correct in light of evidence that responses on a VHF-valence task can be completely reversed by a few minutes of motor training. Reinterpreting VHF-emotion tasks in terms of body-specific space-valence associations – rather than hemispheric specialization – reconciles a large body of behavioral data with newer neuroimaging data that cast doubt on the seemingly well-supported “valence model” according to which positive and negative valence were thought to be differently lateralized in the hemispheres (Berkman and Lieberman, 2010; Harmon-Jones, Gable, and Peterson, 2010), thus clarifying theories of the cortical substrates of emotion.

### Motivation and motor action: the sword and shield hypothesis

Neuroimaging studies that have called the hemispheric laterality of *emotional valence* into question have, at the same time, strengthened the evidence for hemispheric specialization of *affective motivation* (Berkman and Lieberman, 2010; Coan and Allen, 2003; Harmon-Jones, 2003). More than seventy EEG studies show approach and avoidance motivational states are differently lateralized in the frontotemporal cortices (Harmon-Jones *et al.*, 2010). At least this is true in right-handers. Decades after the first EEG-motivation study in right-handers was published, there were no tests in left-handers.

Why might a test of motivational asymmetries in left-handers’ brains be fruitful? It is important to state that testing for handedness-related differences in hemispheric specialization is not necessarily of theoretical interest, per se: many of the hemispheric differences that have been documented were weak, unpredicted, unexplained, and their implications for scientific theorizing remain unclear. In the case of affective motivation, however, we had a focused reason for investigating whether the well-established hemispheric asymmetry in right-handers is also found in left-handers.

Emotional states are intimately linked to actions, and to the hands people use to perform them. In centuries past, sword fighters wielded the sword in the dominant hand to approach an enemy, and raised the shield with the non-dominant hand to avoid attack. The tendency to *approach* with the dominant hand and *avoid* with the non-dominant hand is evident in more ordinary motor actions, as well, including reflex actions. When startled, people reflexively raise the non-dominant hand to defend themselves (Coren, 1992), keeping the more skilful dominant hand out of harm’s way, and leaving it free for more complex approach actions.

In right-handers, the left hemisphere is specialized for approach emotions, and the right hemisphere for avoidance emotions (Harmon-Jones *et al.*, 2010). This means that, for right-handers, approach motivation is co-lateralized with the neural circuits primarily responsible for control of the dominant hand, and avoidance motivation with the circuits responsible for control of the non-dominant hand. This may be no mere coincidence. Approach motivation may be co-lateralized with dominant-hand motor control *because* the dominant “sword hand” is used preferentially for approach actions. Likewise, avoidance motivation may be co-lateralized with non-dominant-hand motor control because the non-dominant “shield hand” is used for avoidance actions. This is the *sword and shield hypothesis* (SSH; Brookshire and Casasanto, 2012; Casasanto, 2009).

This proposal makes a clear prediction: the hemispheric laterality of approach and avoidance motivation found previously in right-handers should reverse in left-handers, for whom cortical control of the “sword hand” and “shield hand” is reversed. To test this prediction, Geoffrey Brookshire and I measured alpha-band power (an inverse index of neural activity) in right- and left-handers during resting-state EEG, and analyzed hemispheric alpha-power asymmetries as a

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function of the participants' trait approach motivational tendencies (measured by the BAS [behavioral activation system] scale; Carver and White, 1994). Stronger approach motivation was associated with more left-hemisphere activity in right-handers, but with more *right*-hemisphere activity in left-handers – indicating a complete reversal of hemispheric specialization for approach motivation (Brookshire and Casasanto, 2012).

A further study confirmed these EEG results using tDCS (which delivers a weak electrical current to the brain through the skull) to manipulate the level of neural activity in participants' left and right frontal lobes (Brookshire, Graver, and Casasanto, 2013). This study showed that the degree to which approach motivation is lateralized in the left vs. right hemisphere covaries continuously with the strength and direction of the participants' hand dominance, as measured by the EHI.

According to “motivation model” of hemispheric specialization, which is supported by more than a hundred behavioral and neuroimaging studies, the left hemisphere is specialized for approach motivation and the right hemisphere specialized for avoidance motivation. But this conclusion – a cornerstone of affective neuroscience – appears to be incorrect: it appears to be a sampling artifact that resulted from the common practice of testing only strong right-handers in neuroimaging studies. The data demonstrating the body specificity of approach motivation suggest that there is no “approach hemisphere” and no “avoidance hemisphere.” Rather, approach motivation appears to be distributed across both hemispheres, consistent with (and perhaps because of) handedness-related differences in hemispheric specialization for manual motor control.

## **Conclusions**

People with different kinds of bodies think differently, in predictable ways. Even highly abstract thoughts depend, in part, on the ways people interact with the physical environment using their particular bodies. The body shapes the mind on various timescales. To the extent that habits of body-world interaction are stable, the habits of mental representation they encourage should be stable over time; to the extent that they change, mental representations may change accordingly. Many other contextual factors influence the representations people form and the judgments they make, as well, and other factors may override body-specific influences at times. But the body is an ever-present part of the context in which we use our minds, and therefore has pervasive influences on the neurocognitive activity that constitutes our thoughts.

These first tests of the body-specificity hypothesis focused on how handedness, genetic or induced, influences brain and mind. On the basis of this bodily attribute, right- and left-handers tend to form systematically different mental images, create different word meanings, arrive at opposite judgments about the same objects in the world, and have a radically different cortical organization of affective motivation. Our hands are particularly important for interfacing with the physical and social environment, but there may be nothing special about the mechanisms by which using our hands shapes our brains and minds (e.g. associative learning), and body-specificity effects should extend beyond the initial test bed of handedness. The ways in which cognitive scientists could discover that bodily differences lead to cognitive differences are limited only by our imaginations.

Like research on linguistic relativity and cultural relativity, investigations of bodily relativity elucidate how patterns of experience give rise to corresponding habits of thinking, feeling, and communicating: how experience shapes our brains and minds. A further challenge is to determine how influences of linguistic, cultural, and bodily experiences combine to shape our mental lives.



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