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Individual differences in the rubber-hand illusion: Predicting self-reports of people's personal experiences

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ABSTRACT

Can we assess individual differences in the extent to which a person perceives the rubber-hand illusion on the basis of self-reported experiences? In this research, we develop such an instrument using Rasch-type models. In our conception, incorporating an object (e.g., a rubber hand) into one's body image requires various sensorimotor and cognitive processes. The extent to which people can meet these requirements thus determines how intensely people experience and, simultaneously, describe the illusion. As a consequence, individual differences in people's susceptibility to the rubber-hand illusion can be determined by inspecting reports of their personal experiences. The proposed model turned out to be functional in its capability to predict self-reports of people's experiences and to reliably assess individual differences in susceptibility to the illusion. Regarding validity, we found a small, but significant, correlation between individual susceptibility and proprioceptive drift. Additionally, we found that asynchrony, and tapping rather than stroking the fingers constrain the experience of the illusion.

1. Introduction

By simultaneously stroking a person's concealed hand together with a visible fake one, people start to sense the fake hand as an actual part of their own body (Botvinick & Cohen, 1998). In this so-called rubber-hand illusion, the central nervous system categorizes a foreign object, for example a rubber hand, as a part of the body. The cognitive and sensorimotor mechanisms underlying such body image incorporations include visuotactile integration (e.g., Armel & Ramachandran, 2003), and the detection of body-specific sensorimotor contingencies (e.g., Botvinick, 2004). At the same time, the strength of illusion appears to be modulated by an internal model of what the human body is like: Objects that differ morphologically from the human body are less easily incorporated (e.g., de Vignemont, Tsakiris, & Haggard, 2006; Tsakiris & Haggard, 2005). The rubber-hand illusion has been used extensively as an experimental paradigm in research aimed at understanding the mechanisms behind our sense of embodiment (e.g., Longo, Schüür, Kammers, Tsakiris, & Haggard, 2008), personal impressions of body-ownership and self-consciousness (e.g., Ehrsson, Spence, & Passingham, 2004; Lenggenhager, Tadi, Metzinger, & Blanke, 2007), or self-other merging (e.g., Paladino, Mazzurega, Pavani, & Schubert, 2010).

To assess the extent to which the fake hand is incorporated in the body image, research has relied heavily on the measurement of proprioceptive drift (i.e., the degree to which people misperceive the location of their concealed hand as being shifted toward the fake hand; e.g., Tsakiris & Haggard, 2005). Empirical evidence, however, suggests that this drift in proprioception might not be a valid indicator of the rubber-hand illusion (e.g., Holmes, Snijders, & Spence, 2006; Folegatti, Farnè, Salemme, & de Vignemont, 2012; but see Longo et al., 2008). Rohde, Di Luca, and Ernst (2011) have even argued that the rubber-hand illusion is perhaps better assessed using people's descriptions of what the rubber-hand illusion feels like. These descriptions, however, vary widely between individuals. Some people claim, for example, that they felt as if they could move and use the fake hand (i.e., a sense of agency; Haans, IJsselsteijn, & de Kort, 2008). Other people, under similar experimental conditions, claim that they even saw the fake hand changing appearance (i.e., a case of altered visual perceptions; Lewis & Lloyd, 2010). Still others appear to be relatively insensitive to the illusion, as the descriptions of their experiences are limited to impressions of strangeness and confusion. The question is: Is this apparent variability in reports about the rubber-hand illusion largely irrelevant? Should it be regarded as noise in the data? Or, alternatively, are these reports of various personal experiences valid indicators of people's differential susceptibility to the illusion?

In this paper, we present two experiments in which we test a model that predicts self-reports of how a person experiences the rubber-hand

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illusion. In a first experiment, we investigate whether individual differences in the susceptibility to the rubber-hand illusion can be used to determine how people describe their personal experiences. In a second experiment, we extend our model to include the effects of experimental manipulations of the situation in which the illusion is elicited (e.g., the amount of asynchrony in the visuotactile stimulation). Before doing so, we discuss research employing Botvinick and Cohen (1998), which is thought to capture experiences related to the rubber-hand illusion.

1.1. Self-reported experiences

The measure by Botvinick and Cohen (1998) consists of nine statements regarding specific experiential effects presumed to be related to the rubber-hand illusion. If we compare the various studies that have used the instrument, then it becomes apparent that there is a consistent order with respect to how frequent these various statements are agreed upon (e.g., Ehrsson et al., 2004; Peled, Ritsner, Hirschmann, Geva, & Modai, 2000; see also Holmes & Spence, 2007). The three most frequently endorsed statements relate to the location of felt touch (e.g., feeling the touch in the location where one sees the rubber hand being touched), and to a sense of ownership toward the fake hand (e.g., the fake hand feels as one's own). The remaining six statements are much less frequently endorsed (e.g., relating to distortions in the perceived appearance of the fake hand). For most people, these latter statements apparently do not match their experiences.

Some authors have argued that the rarely supported items refer to experiential effects that are unrelated to the illusion (e.g., Ehrsson et al., 2004). Consider, however, two items in a mathematical test: an addition and an integration task. Fewer people will correctly solve the integration than the addition task. This is not because integration is less of a mathematical problem than addition. Instead, integration problems require rather more mathematical skills than addition problems in order to be solved correctly. In other words, the addition and the integration item both need to be matched with a certain level of mathematical ability. We propose an analogous look at the items of Botvinick and Cohen (1998) instrument. The least frequently acknowledged experiential effects are the ones that, in order to be experienced, have to be matched with a high level of a specific ability. We call this ability "susceptibility to the rubber-hand illusion."

1.2. Individual susceptibility as an ability

Individual differences in people's susceptibility to the rubber-hand illusion are rather likely, not the least, because individual differences are common with other bodily illusions as well (e.g., MacLachlan, Desmond, & Horgan, 2003; Mussap & Salton, 2006). These differences might derive from differential information processing capabilities (e.g., with respect to visuotactile integration; Peled et al., 2000), or from differences in people's psychological makeup (Juhel & Neiger, 1993). People may, for example, differ in the stability of their body image (Mussap & Salton, 2006). Burrack and Brugger (2005) found the frequency of spontaneous body image alterations in everyday life to be correlated with people's susceptibility to experimentally induced bodily illusions. The less stable one's body image is, the more likely it is to be sensitive to change due to novel sensorimotor information.

Susceptibility to the rubber-hand illusion reflects the extent to which a person can activate the required sensorimotor and cognitive processes (e.g., visuotactile integration), and inhibit others (e.g., comparing the foreign object with an internal model of the human body). Vice versa, we expect that each experiential effect related to the rubber-hand illusion (e.g., a sense of ownership over the fake hand) demands certain cognitive and sensorimotor processes to be activated or inhibited. We call these experience-specific requirements "cognitive demand". If a person's susceptibility does not match the cognitive demand behind a particular experiential effect, then he or she will not develop, and thus not report, that experience.

1.3. A transitive order of experiential effects

Cognitive demand is defined as a property of an experiential effect (e.g., fake hand feels as one's own), and is assumed independent of the individual on whom the rubber-hand illusion is induced. A more susceptible person has better chances of developing and thus reporting a particular experiential effect compared to a less susceptible individual, but the cognitive demand behind that experience is the same for both. In other words, we expect the cognitive demand behind each experiential effect to be more or less the same for everyone. This rests on the assumption that the cognitive and sensorimotor requirements behind body image incorporations are more or less the same for each individual. Note that a similar assumption is made in cognitive psychology, where it is assumed that the cognitive processes behind mental capacities are equivalent for healthy adults.

If this invariance of cognitive demands assumption holds, then all experiential effects related to the rubber-hand illusion can be transitively ordered according to their cognitive demand in a manner that is the same for everyone. An order of objects is called transitive under the conditions exemplified by the following: If experience A is more demanding to develop than experience B, and B is more demanding than experience C, then A must be more demanding than C. This transitive and invariant order of experiential effects implies that a person's susceptibility to the rubber-hand illusion manifests itself in a determined, and thus predictable, set of reported experiences (i.e., all but the too demanding ones).

For people who are marginally susceptible to the rubber-hand illusion, the illusion presumably is limited to impressions of confusion and strangeness as such experiential effects only require registering the contradiction in the sensory information (cf. Armel & Ramachandran, 2003). Such unreceptive individuals will not experience and thus not report a stronger rubber-hand illusion as they do not meet the necessary cognitive requirements.

More susceptible individuals, by contrast, are expected to also develop impressions of some tactile sensations that originate from the fake hand. Such experiential effects are relatively demanding as they require uniting contradicting visual and tactile information into a single percept. Even more demanding are impressions that require a recalibration of the mental representation of one's body image, such as experiencing the fake hand as part of one's body.

Only those few individuals that are extremely susceptible to the illusion are expected to encounter visual changes in the appearance of the fake hand, as this is presumed to require a prolonged feeling of ownership over the fake hand (see Lewis & Lloyd, 2010). These people will not only report altered visual perceptions, but are also expected to experience a sense of ownership over the fake hand, a relocation of felt touch, and impressions of strangeness and confusion.

Thus, if our assumption of an invariant and transitively ordered set of experiential effects holds, then we can predict how a person experiences, and thus reports on, the rubber-hand illusion on the basis of an estimate of his or her susceptibility to the illusion. The specific transitive order of increasingly demanding experiential effects ultimately defines the rubber-hand illusion. In our conception, all experiential effects related to the rubber-hand illusion fall onto a single continuum rather than being organized into a set of multiple dimensions (cf. Longo et al., 2008). Since multidimensional conceptions of the rubber-hand illusion require a matching number of individual abilities, our model offers a more parsimonious account of the individual differences in people's reports about the illusion.

1.4. A Rasch model implementation

The hypothesized relationship between a person's self-reported experiences, his or her susceptibility to the illusion, and the presumed cognitive demand behind each specific experiential effect can be