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Measures of agency

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Abstract

The sense of agency is typically defined as the experience of controlling one's own actions, and through them, changes in the external environment. It is often assumed that this experience is a single, unified construct that can be experimentally manipulated and measured in a variety of ways. In this article, we challenge this assumption. We argue that we should acknowledge four possible agency-related psychological constructs. Having a clear grasp of the possible constructs is important since experimental procedures are only able to target some but not all the possible constructs. The unacknowledged misalignment of the possible constructs of a sense of agency and the experimental procedures is a major theoretical and methodological obstacle to studying the sense of agency. Only if we recognize the nature of this obstacle will we be able to design the experimental paradigms that would enable us to study the responsible computational mechanisms.

Keywords: agency; intention; volition; consciousness; methodology; theories and models; sense of agency; construct validity

Introduction

The sense of agency is typically defined as the experience of controlling one's own actions, and through them, changes in the external environment. It is often assumed that this experience is a single, unified construct that can be experimentally manipulated and measured in a variety of ways. In this article, we challenge this assumption. We provide conceptual and experimental reasons for the claim that studies of the sense of agency have been studying a number of different agency-related phenomena.

Recent research conceives of the conscious sense of agency as grounded in the mechanisms of action control, ranging from early mechanisms of action selection to later mechanisms of evaluation (Haggard and Chambon 2012). Supporting this conception, some studies have reported that a reduced sense of agency is related to a reduced fluency of action selection (Wenke et al. 2010; Chambon et al. 2014), whereas others have

reported that binding between actions and effects are related to judgements of agency (Schwarz et al. 2018a). One central assumption for this conception of the sense of agency and the underlying action-control mechanisms is that the various stages of the process of action-control contribute to a single and unified sense of agency.

This conception is challenged by a growing number of studies reporting a lack of correlation between measures supposed to gauge different aspects of one single construct: the sense of agency. For instance, some studies correlating separate measures supposed to track sensorimotor predictions of action-effects (intentional binding and sensory attenuation) have not been able to find any significant relation (Dewey and Knoblich 2014; Borhani et al. 2017). Moreover, these implicit measures have turned out not to be correlated with explicit measures of the sense of agency (Schwarz et al. 2019). Assuming that these experimental procedures study different but tightly related aspects of the action-control mechanism underlying a unified

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experience of agency, we should expect significant correlations between the measures (Beck et al. 2017).

In this article, we argue that the sense of agency is no single construct. Instead, we argue that we should acknowledge four possible psychological constructs. This part of the argument is conceptual. Having a clear grasp of the possible constructs is important since experimental procedures are only able to target some but not all the possible constructs. The unacknowledged misalignment of the possible constructs of a sense of agency and the experimental procedures is a major theoretical and methodological obstacle to studying the sense of agency. Only if we recognize the nature of this obstacle will we be able to design the experimental paradigms that would enable us to study the responsible computational mechanisms.

We proceed as follows. In Four senses of agency, we argue that a cognitive neuroscience of the sense of agency should distinguish between, on the one hand, ability and phenomenal character forms of sense of agency, and, on the other hand, bodily and external forms of sense of agency. The two distinctions combine to define four different psychological constructs. In the section Sense of agency procedures, we argue that the conceptual distinctions are mirrored in distinctions between experimental procedures. Some psychological measures target a sense of agency as a cognitive ability, whereas others target it as a phenomenal character. Some experimental manipulations target a bodily sense of agency, whereas others target an external sense of agency. These constraints are rarely acknowledged in the experimental literature. In the section Measuring the phenomenal character of the sense of agency, we argue that due to the nature of action tasks, there are reasons for suspecting that current procedures are not able to systematically study a sense of agency as a phenomenal character. In Construct validity, we argue that the unacknowledged misalignment of a plurality of constructs and the standard experimental paradigms leads to a general low construct validity of sense of agency studies. One consequence is that too often we remain unable to determine exactly what psychological phenomenon an experimental procedure is really targeting.

Four Senses of Agency

In this section, we argue that the standard use of the notion of a sense of agency in cognitive neuroscience is ambiguous between four different possible constructs (ability vs phenomenal feel and bodily vs external, see Fig. 1A). As long as studies do not specify which construct they are targeting, the experimental procedures will be threatened by low construct validity (see Construct validity section).

Ability sense of agency vs phenomenal character sense of agency

Often, researchers do not notice that there are important differences between conceiving of a sense of agency as a cognitive ability or as a distinctive phenomenal character. The sense of agency as an ability can be considered as a cognitive function that enables us to answer the question of ‘who’ is the agent of an action or who is the cause of an event. Sense of agency as a phenomenal character has to do with what it is like to control one’s action, and through it, events in the world. This conceptual distinction is an instance of a general distinction between conceiving a consciousness as a cognitive function or as a non-cognitive phenomenal character. This general distinction manifests itself in an important theoretical conundrum.

Theoretically, it seems impossible to define phenomenal consciousness as a set of well-specified functional roles, but, methodologically, it seems equally impossible to experimentally study phenomenal consciousness without assuming that it plays some causal role.

In philosophy, this problem has been well known since Block’s discussion of the troubles with functionalism (Block 1978). Consider some functionalist definition of consciousness. A mental state is conscious if and only if the state plays the causal role x in the cognitive system (for instance, the informational state has been funnelled into working memory by attentional mechanisms, Prinz 2005). Now, for any causal functional characterization that specifies the conditions for consciousness, we can imagine some physical system (for instance, a very big group of people where the members are connected to each other by ‘walkie-talkies’) that realizes the causal function but where we can agree the system is not conscious. Consequently, having a cognitive function is not sufficient for consciousness. But neither is it necessary. That is, we cannot rule out the possible existence of conscious creatures in which the conscious state does not satisfy the functional description (Block 1995). One worry against this kind of argument is that it pushes us to accept that consciousness plays no representational and functional role in human psychology. This looks suspiciously like epiphenomenalism about consciousness (Dennett 1988).

In psychological science, we witness a similar dialectic between cognitive and non-cognitive theories of consciousness. Some psychologists define consciousness in terms of functional role. Let us focus on the association of consciousness with the functional role of attention. A cognitive theory of consciousness will typically defend the claim that attention is necessary for consciousness (Jacoby et al. 1997; De Brigard and Prinz 2010) and that consciousness is necessary for a number of cognitive operations (for instance, for explicit information maintenance, semantic processing, flexible and novel combinations of cognitive operations, or spontaneous initiation of intentional action, McGovern and Baars 2007; Dehaene 2014).

Against such functional characterizations, it seems never too difficult to design some experiment that can demonstrate versions of the cognitive function (say, attention or working memory) in the absence of consciousness (Kentridge et al. 1999; Soto et al. 2011). Furthermore, there are introspective reasons for accepting that consciousness ‘overflows’ the scope of attention, working memory and reportability (Block 2011). The non-cognitive conclusion is that attention and working memory are neither sufficient nor necessary for consciousness. Similar to the philosophical discussions, one might worry that the non-cognitive conclusion has the consequence that consciousness becomes impossible to study. To study consciousness in psychological experiment, we need to assume that it plays some systematic causal role (Kouider et al. 2010; Overgaard and Grünbaum 2012; Phillips 2018).

Summing up, when studying consciousness, we need to decide whether or not we conceive of consciousness as playing a cognitive role. If we identify consciousness with some cognitive function, the problem is that it always seems possible to find instances of the function in the absence of consciousness. If we insist that consciousness is something other than possible cognitive functions, the problem is that consciousness seems epiphenomenal and impossible to study systematically.

One reason why this conceptual choice is so important in cognitive psychology is that it aligns with a choice of experimental paradigms. If one associate consciousness with a specific set of cognitive functions, one can study consciousness by

A		Bodily	External	B	
Phenomenal character	<p style="text-align: center;">Construct 1</p> <p>A distinctive feeling of activity associated with the voluntary performance of particular movements.</p> <p>What it feels like to move your own body and be in control of it's movements</p> <p>(e.g. Desmurget et al., 2009, Bayne, 2011).</p>	<p style="text-align: center;">Construct 3</p> <p>A distinctive feeling of being in control over changes in the environment.</p> <p>What it feels like to exert control over events in the environment</p> <p>(e.g. Kühn, Brass, & Haggard, 2013, Wenke et al., 2010)</p>	Phenomenal character	<p style="text-align: center;">Construct 1</p> <p>Externally induced illusion of movements</p> <ul style="list-style-type: none"> • Direct cortical stimulation during neurosurgery (Desmurget et al 2009) • TMS induced illusion of movement (Amassian et al 1989, Christensen et al 2012) 	<p style="text-align: center;">Construct 2</p> <p>Action-effect manipulation using graded scale of control or introspective report</p> <ul style="list-style-type: none"> • Visual image of virtual hand (Nahab et al 2011) • Another person's hands (Wagner et al 2004)
Ability	<p style="text-align: center;">Construct 2</p> <p>An ability to distinguish between voluntary and passive movements on the basis of signals from the performance of particular movements.</p> <p>(e.g. Blakemore, 2003, Christensen & Grünbaum, 2018).</p>	<p style="text-align: center;">Construct 4</p> <p>An ability to distinguish between events caused by oneself and events caused in some other way on the basis of many sources of signals and background beliefs.</p> <p>(e.g. Daprati et al., 1997, Farrer et al. 2008)</p>	Ability	<p style="text-align: center;">Construct 3</p> <p>Temporal order judgment</p> <ul style="list-style-type: none"> • Judgment of the order of a voluntary movement and an electrical stimulation (McCloskey et al 1983) 	<p style="text-align: center;">Construct 4</p> <p>Feedback manipulation using self-other categorization as measure</p> <ul style="list-style-type: none"> • Line drawings with temporal or spatial distortions (Farrer et al. 2006) • Line drawing with spatial distortion (Foumet & Jeannerod, 1998)
			Sensory attenuation	<p style="text-align: center;">Construct 4</p> <p>Manipulation of self/other generated tactile sensory event</p> <ul style="list-style-type: none"> • Sensation of ticklishness (Blakemore et al., 1999) 	<p style="text-align: center;">Construct 5</p> <p>Action-effect manipulation</p> <ul style="list-style-type: none"> • Judgment about stimulus intensity (Dewey & Knoblich, 2014) • Suppression of EEG signal (Timm et al., 2016)

Figure 1. (A) The 2-by-2 construct of sense of agency: phenomenal character vs ability and bodily vs external. (B) Division of experimental procedures into bodily or external sense of agency by asking whether the procedures manipulate properties of the movement or properties of the external event. Division of experimental procedures into phenomenal or ability sense of agency by asking whether they use a subjective scale or performance accuracy as a measure. We provide examples of the different experimental studies, categorized into the four different constructs.

studying the cognitive functions (using the traditional measures of response time and accuracy). If one conceives of consciousness in non-cognitive terms, one will usually use paradigms with introspective reports and implicit neural measures. Note that introspective reports are here assumed to express or report on the phenomenal character of an experience (for instance, the sharpness of one's pain), where one's introspective reporting might be by verbal or some other communicative means. Note also that not all verbal reports are introspective reports. For instance, a verbal report of the number of items in a display will usually not count as an introspective report.

With respect to the sense of agency, we find a similar split between conceptualizing the experience in terms of a cognitive function (ability) or as a non-cognitive phenomenal character. Notice that the conceptual distinction between conceiving of a sense of agency as a cognitive ability or as a non-cognitive phenomenal character is orthogonal to the distinction between a low-level sense of agency as an experience and a high-level judgement of agency (Synofzik et al. 2008). Irrespective of whether one conceives of a sense of agency as a cognitive ability or phenomenal character, one can make the distinction between *sense of agency* and *judgements of agency*.

Focusing first on the sense of agency as a *cognitive ability*, one motivation for studying the sense of agency has been the identification of the sense of agency with the agent's ability to recognize her own movements. One important hypothesis has been that this ability to identify oneself rests upon the ability to assign the correct agent to a movement, i.e., that oneself is the agent of the movement as opposed to the movement being another agent's action (Georgieff and Jeannerod 1998; Jeannerod 2006). Perhaps the most basic form of action-recognition is a kind of sensorimotor identification in which predictions of sensory consequences of a movement are confirmed by sensory feedback (for instance, proprioceptive, tactile, and visual feedback). This kind of sensorimotor identification has been studied by looking at automatic compensatory movements in versions of the Nielsen paradigm (see Fournet and Jeannerod 1998, for discussion of the paradigm, see below).

Identifying the conscious sense of agency with a basic sensorimotor ability to make self-other discrimination can in some

situations seem problematic. It seems that the function of sensorimotor-based self-identification is conceptually independent of a conscious sense of agency. First, plausibly, agents are able to discriminate their own movements in the absence of conscious awareness. In other words, we can have action identification without a conscious sense of agency (as argued by Jeannerod 2009). Second, we can also have a conscious sense of agency without sensorimotor-based action identification. At least it is not obvious that the type of situation where cortical stimulation is supposed to induce a conscious agency-like experience associated with movement (for instance, Desmurget et al. 2009) is a situation where action identification is computationally required. In short, just as an in the studies of consciousness, there are instances of the cognitive operation in the absence of a conscious sense of agency and possibly also instances of a conscious sense of agency in the absence of the cognitive operation. In other words, the cognitive ability (for instance, sensorimotor-based action identification) seems to be neither necessary nor sufficient to the *conscious* sense of agency.

Turning now to the other side of the conceptual split. A number of researchers understand the sense of agency not as a particular kind of cognitive ability but as a specific type of phenomenal feel. According to this view, we should identify the sense of agency by how it feels (not by what it does). For instance, one might define the sense of agency as 'a definite background feeling or buzz of being in control' (Kühn et al. 2013, p. 1936). Instead of defining a sense of agency as something the agent can do or operations the system can perform, it is defined as a distinctive feeling or phenomenal character produced by certain neural mechanisms. Often, this phenomenal character sense of agency has been tied to comparator mechanisms assumed to be crucial to motor control (Haggard and Chambon 2012).

Identifying the conscious sense of agency with a non-cognitive phenomenal character can also seem problematic in some situations. To begin, studying the phenomenal sense of agency in behavioural experiments presupposes that the sense of agency plays some systematic causal role in generating the behaviour identified as the dependent variable. Some researchers think that the phenomenal character of sense of agency

plays only a minimal causal role in generating introspective reports (and hence as inputs to belief formation, see, for instance, Wegner 2002), whereas others think a phenomenal sense of agency plays a more substantial role in motor cognition (Haggard 2017).

One way to characterize the phenomenal sense of agency as playing a more substantial causal role is to associate the phenomenal character with the output of certain neural comparator mechanisms hypothesized to be central to motor control. However, tying the phenomenal sense to this kind of mechanism does not help us understand the causal role played by the phenomenal sense of agency. Whatever functional role the comparator mechanism is playing for motor control and action identification, it is not hard to imagine that it can play this role without producing any conscious sense of agency (Zaadnoordijk et al. 2019). Furthermore, the comparator's matching of predicted and actual feedback is often thought to work by subtraction. A complete match means that the prediction cancels out the actual sensory feedback. The result should be the cancelling or dampening down of signals (not the production of positive signals) (for a discussion of this point, Christensen and Grünbaum 2017). Given the absence of a functional role for the phenomenally conscious sense of agency, it becomes problematic how we should measure it.

Summing up this part, researchers have to make a choice between conceiving of the conscious sense of agency as a cognitive ability or a distinctive non-cognitive phenomenal character. This choice is an instance of a more general choice between cognitive and non-cognitive theories of consciousness. As an instance of this more general choice, the ability view and the phenomenal character view are each confronted with a set of problems—in so far as these views are understood as exhaustive definitions of a conscious sense of agency. In the domain of motor control and sense of agency, this choice has important methodological consequences. If you opt for an ability view, then various action recognition paradigms will be the standard choice of experimental paradigms. If you adopt a phenomenal feel view, then various introspective paradigms might seem more appealing (paradigms where participants are asked to assess the strength of their sense or feeling of agency). We will return to the experimental paradigms below.

Bodily sense of agency vs external sense of agency

The above distinction can be combined with a distinction between bodily and external conceptions of the sense of agency (Christensen and Grünbaum 2017, 2018; Solfo and van Leeuwen 2018; Wen 2019—see Fig. 1A). According to a bodily conception, the sense of agency is related to the performance of specific bodily movements, whereas according to an external conception, the sense of agency is associated with the planned environmental consequences of one's action. Thus, some researchers define the sense of agency in relation to movements (for instance, Christensen and Grünbaum 2018, p. 37: '[participants] report whether they themselves had performed a movement of the index finger'). Some researchers emphasize the control of external events (for instance, Wen et al. 2016, p. 1: 'The ubiquitous experience of a subjective feeling of control over the outcome of events through one's behaviour refers to sense of agency'). Most often, however, researchers mention the sense of agency without any consideration of the distinction between bodily and external characterizations (for instance, Haggard 2017).

Disregarding the distinction between bodily and external conceptions of the sense of agency is problematic for a number of reasons. The ability and phenomenal feel conceptions each come in bodily and external versions. The bodily version of the ability view is assumed by Blakemore (2003). According to Blakemore, the sense of agency is the ability to identify a movement as being self-produced. By contrast, Fournier and Jeannerod (1998) assume the external version of the ability view. According to these researchers, the sense of agency has to do with the ability to recognize consequences of one's movements as being caused by oneself. The bodily version of the phenomenal feel view is assumed by Bayne (2011). Here, the focus is on the distinctive feeling of movement activity. Finally, some researchers adopt an external version of the phenomenal character view according to which a distinctive feeling of agency is associated with planned consequences of one's action. This conception is adopted by Haggard and Tsakiris (2009) and Kühn et al. (2013).

There are reasons for thinking that bodily and external forms of sense of agency are realized by different mechanisms, even if these mechanisms are governed by the same type of predictive comparator principles. First, if we assume that the sense of agency is best explained by a comparator model (for a review, see Christensen and Grünbaum 2018), then we should distinguish between the mechanisms for bodily and external sense of agency. The comparator mechanism might be a plausible explanation of a bodily sense of agency. That is, one plausible explanation of the bodily sense of agency is to describe it as the output of a neural comparator mechanism that takes as input sensory predictions computed from motor commands and sensory feedback from the actual performance produced by the motor commands.

The same comparator mechanism is not a plausible explanation of an external sense of agency. One of the reasons for this is that if we compare the external consequences with the movements that produce them, the external consequences are usually delayed or mediated through some tool, device or apparatus. Predicting external consequences requires that knowledge about the delays and mediators can be incorporated into the comparator model. If I turn the key in my car, it takes a little while before the engine starts. In order to make the prediction that my movement (rotating my hand) will make the engine hum (i.e. start the engine), beliefs about how an engine works or prior experience with this type of action are required. Similarly, predictions about auditory events as a consequence of a button press build on prior beliefs about the relevant devices and their delays. It is a plausible assumption that a system using copies of motor commands to compute predictions of internal sensory feedback is relatively cognitively insulated and modular, with a relatively fixed knowledge base of associations between motor signals and proprioceptive sensory consequences. It is much less plausible that the same could be said of a system that computes predictions of external sensory events. It is unlikely that the same mechanism computing a prediction of somatosensory and proprioceptive feedback from copies of motor signals is also able to predict the auditory event of the humming engine.

So, while it is likely that the same type of computational principle can support both types of prediction, it seems unlikely that they are realized by the same computational mechanisms. Both the computational mechanism involved in predicting proprioceptive sensations of movements and the computational mechanism involved in predicting perceived events in the world beyond the body might be governed by the same

predictive or Bayesian principles, but they would compute over different types of input. One comparator mechanism produces predictions of proprioceptive sensations on the basis of motor commands, whereas the other comparator mechanism predicts perception of distal events on the basis of many types of information. Furthermore, one can assume that these predictive mechanisms rely on different types of learned associations, as well as different types of associative strength. This kind of difference between a comparator mechanism for movement and for distal effects has been confirmed by a recent fMRI study by [Uhlmann et al. \(2020\)](#) indicating that recognition of one's own hand rely on information specifying hand identity. Prior establishment of hand identity is not needed when the brain computes a sense of agency for the movement.

Second, if we assume that the sense of agency is best explained by motor commands or efferent signals alone ([Tsakiris and Haggard 2005](#); [Christensen and Grünbaum 2018](#)), we are again forced to distinguish between the mechanisms for bodily and external sense of agency. Motor commands might explain a bodily sense of agency related to particular movements but it is difficult to see how they could explain an external sense of agency for the events brought about by one's movement. To explain the external sense, we would have to include other sources of information as well. Taken together, this gives us good reasons to assume a difference between a bodily and an external sense of agency.

It could be objected that the distinction between bodily and external sense of agency is arbitrary. One could have pointed to different aspects of the experience of voluntary movement. For instance, a number of philosophers have pointed to experiences such as the sense of initiation, feeling of effort, sense of purposiveness, and sense of goal-completion (see [Horgan et al. 2003](#); [Bayne 2008](#); [Pacherie 2008](#)). One might claim that since these features are just as important—if not more important to our understanding of agency—as the distinction between a bodily and external sense of agency, and they cut across our distinction, our distinction seems arbitrary or unmotivated.

The philosophical literature has undoubtedly unearthed many important dimensions of conscious agency. Our concern has, however, not been to provide a conceptual or phenomenologically satisfying description of the conscious aspects of intentional agency. Our main aim has been to describe a few salient distinctions grounded in mechanistic knowledge and their fit with experimental practise (see Sense of agency procedures section). A distinction like the one between sense of initiation and sense of completion might be interesting but it does not, to our knowledge, fit with a distinction between types of experimental paradigms.

This gives us a conceptual two-by-two structure (see [Fig. 1A](#)). Conceptually, abilities and phenomenal character are two distinct kinds of attribute, and so are external and bodily forms of the sense of agency. Plausibly, these two conceptual distinctions carve out four possible psychological attributes: external vs bodily sense of agency as an ability and external vs bodily sense of agency as a phenomenal feel. These distinctions are important. Cognitive neuroscientists studying the sense of agency tend to be oblivious of the fact that the notion of the sense of agency is ambiguous with respect to four possible attributes.

Sense of Agency Procedures

The two conceptual distinctions and their four combinations are important because of how they connect with experimental

procedures. On the one hand, whether an experimental procedure studies a bodily or an external sense of agency depends on the experimental manipulation. Roughly, if the paradigm manipulates the bodily movement, it is targeting a bodily sense of agency; whereas if the paradigm manipulates an external event, it is targeting an external sense of agency. On the other hand, whether a procedure studies an ability or a phenomenal character sense of agency depends on the type of measure. Roughly, if it makes sense to use accuracy as a measure, the paradigm is targeting an ability sense of agency; whereas if the paradigm uses an introspective measurement scale or an implicit measure (intentional binding or sensory attenuation), it is targeting a phenomenal character sense of agency. This is a rough generalization. The experimental reality is bound to be more complex with possible borderline cases, hybrid situations and exceptions. Let us illustrate this classification with a few paradigmatic experimental studies.

External + ability sense of agency

Experimental paradigms fall into this category if they work by manipulating external events and measuring accuracy. There are broadly speaking two types of experimental designs used to study the external sense of agency conceived as a cognitive ability: feedback manipulation studies and action-effect studies.

First, some studies have used a general design where the ongoing sensory feedback signal (typically visual) is manipulated. A prototypical example is computerized version of the alien hand experiment ([Nielsen 1963](#)) by [Fournier and Jeannerod \(1998\)](#). In this experiment, line drawing movements are transformed into a visually distorted version of the same line drawing movement. The distortions of visual feedback can either be of a spatial or temporal nature, i.e., angular deviations or delays ([Farrer et al. 2008](#)). A typical measure would be participants' accuracy in determining deviations between their own movement and the visible line drawing.

Second, some studies have used a design where participants perform an action that produces some event (an action-effect design). Most action-effect studies are combined with a subjective scale measure (see External + phenomenal character sense of agency section) but a few have used accuracy and response time measures. For instance, in a study by [Spengler et al. \(2009\)](#), participants initially had to press one of two buttons with their index or middle finger related to a subsequent appearance of a red or blue square, whereby they learned the association between an action and its effect. In the real experiment, a computer controlled the outcome and the participant had to evaluate whether they agreed or disagreed with the statement that they produced the square.

External + phenomenal character sense of agency

In this category, we find studies that manipulate an external event while gauging the phenomenal sense of agency by some kind of subjective scale of agency or an implicit measure thought to reliably index the phenomenal sense. Often, these types of paradigm do not easily allow for any assessment of correctness according to some objective behavioural standard. As above, we can divide studies into feedback manipulation studies or action-effect studies. Let us just mention one typical study of each subcategory.

A typical design combining manipulation of visual feedback and subjective ratings is provided by [Nahab et al. \(2011\)](#). Here, the participants wore a cyber-glove over their hand. They were

presented with a computerized version of the hand's movements, which could be manipulated to different degrees. At the completion of each block, the participants were asked to 'report the level of control experienced over the simulated hand, rating anywhere from 0% (no control) to 100% (full control)'.

As an example of a study combining the manipulation of action-effects with introspective ratings, consider a now-classic paradigm introduced by [Sato and Yasuda \(2005\)](#), in which participants first learned an association between two actions (press of a button with their left or right hand) and two effects (600 or 1000 Hz tones) following the actions immediately. In the test phase, participants were pressing the two buttons and subsequently hearing tones, but the tone could be either the same as (congruent) or different (incongruent) than the tone they had learned in training normally follows the button press. Also, the tone could follow the action immediately, as participants learned it normally does, or after a delay (200, 400 or 600 ms). Participants were informed that on some trials the experimenter would produce the tone, although this was not true. After each trial (button press and a tone), participants were asked to answer two questions on a scale from 0 ('totally disagree') to 100 ('totally agree'): 'I was the one who produced the tone' (supposed to measure the 'sense of self-agency') (we discuss a different type of action-effect paradigm in Transparency of agency task section). (Note that the sentence 'I was the one who produced the tone' is ambiguous between an 'ability reading' according to which it is a judgement about the causal origin of the tone (can be assessed for correctness) or a 'phenomenal character reading' according to which it is a judgement about the strength of an inner experience (cannot be assessed for correctness). [Sato and Yasuda \(2005\)](#) presumably intend the latter introspective reading.)

Worries about the inter-trial reliability of subjective ratings have led researchers to search for some implicit measure of the phenomenal sense of agency. One of the most influential series of action-effect studies is an implicit version of the design ([Haggard et al. 2002](#); [Moore and Obhi 2012](#); [Wolpe and Rowe 2014](#)). In the operant condition, participants have to perform actions (a button press) that causes an auditory tone to appear after a 250 ms interval. Participants perform a temporal judgement (using a rotating Libet clock) of when they performed the action or when they heard the tone. These judgements are compared with control situations with temporal judgement of the action or the tone separately. The apparent temporal attraction of the judged time of the action and the judged time of the effect is the so-called intentional binding effect, because it seems to appear only when the action is voluntarily produced ([Haggard et al. 2002](#)).

The temporal binding phenomenon is often assumed to be an implicit measure of sense of agency ([Moore and Obhi 2012](#)). In some experiments, a direct estimation of the temporal interval is also used ([Dewey and Knoblich 2014](#); [Imaizumi and Tanno 2019](#)). Recent data suggest that the binding effect is mainly driven by predictability of the action-effect events ([Kirsch et al. 2019](#)). These data suggest that the binding is also present in the case of involuntary actions-effect relations that are predictable, indicating that the binding effect is a general phenomenon ascribed to causal inference rather than a matter of intentionality ([Buehner 2012](#)).

It remains unclear what the binding studies are actually measuring in relation to explicit measures of agency. The manipulation of the interval between the action and the effect produces systematic variations in explicit judgements of agency ([Schwarz et al. 2019](#)), but the effect on implicit measures of

agency is more mixed, with some studies suggesting that the intentional binding effect increases with delay ([Humphreys and Buehner 2009](#); [Kühn et al. 2013](#); [Dewey and Knoblich 2014](#); [Wen et al. 2015](#); [Ruess et al. 2017](#)) and others suggesting it decreases ([Ruess et al. 2018](#)). Recently, a number of studies have investigated this relationship between explicit and implicit measures of agency ([Imaizumi and Tanno 2019](#); [Schwarz et al. 2019](#)) with varying results. We return to this issue in Construct validity section.

In conclusion, to study the external phenomenal sense of agency, researchers use either paradigms with an introspective measure or paradigms with an implicit measure (mainly intentional binding). Both types of paradigm are confronted with important problems. As will become clearer in Measuring the phenomenal character of the sense of agency section, for both types of measures, it turns out to be difficult to establish that they are really measuring a distinctive phenomenal sense of agency.

Bodily + ability sense of agency

Studies in this category combine the manipulation of the bodily movement with some kind of accuracy measure. Though difficult to study, the sense of agency in the bodily ability sense is easier to manipulate and measure than the bodily phenomenal sense of agency. In principle, the bodily ability sense of agency can be studied by manipulating whether or not a participant's movement is voluntary, while measuring the participant's ability to discriminate between the voluntary and the involuntary movement conditions. Important to the success of this type of paradigm is the assumption that movements in voluntary and involuntary conditions can be similar with respect to their kinematic and sensory properties. Only few researchers have pursued this line of research. Here we will describe some possible experimental designs.

First, take a recent study by [Christensen and Grünbaum \(2018\)](#) using a mechanical device to make passive finger extension movements. This allowed the authors to make comparisons of voluntary finger extension movements and passive movements of the same fingers. By creating choice conditions that leave some room open for errors in performance, it is possible to create situations where it becomes ambiguous for the participant whether she performed a movement or the mechanical device moved her finger. These two different types of event can be objectively measured by the presence or absence of bursts of muscle activity of the finger extensor muscles using electromyography (EMG). [Christensen and Grünbaum \(2018\)](#) used a standard timing and velocity of the mechanical hand, which matched average reaction times found in pilot experiment. An obvious improvement to their study would be to use EMG-triggered mechanical perturbations with a minimal delay and dynamics that match the individual participant's movement.

Another possible approach to study objectively the ability dimension of bodily sense of agency is to use functional electrical stimulation ([Merletti et al. 1975](#); [Popovic et al. 2002](#); [Christensen and Grey 2013](#)). Here, patterned electrical stimulation of the muscles can be used to augment voluntary movements, or passively activate muscle synergies to make your limbs move without voluntarily making the movements. Unfortunately, it is not possible to induce movements using functional electrical stimulation without the accompanying clear sensation in the skin of a weak electrical stimulus. A matched sensation of electrical stimuli to the skin during a voluntary movement is unfortunately very hard to make without inducing movements. The

different sensation of different stimulation intensities is obvious to the participant. Therefore, it is challenging, though perhaps not impossible, to use functional electrical stimulation to directly study the ability dimension of bodily sense of agency.

A third approach that has been used in some studies is to compare voluntary movements with transcranial magnetic stimulation (TMS) induced muscle twitches (see [Tsakiris and Haggard 2003](#); [Jensen et al. 2014](#)). This also allows for objective measures to compare with judgments of whether it is oneself or the stimulation that induces the movement. Unfortunately, the muscle activity patterns underlying voluntary movements (even for simple finger flexion or extension movements) are very different from the motor evoked potential twitches induced with TMS, which has a distinct temporally locked pattern of EMG activity. Even series or trains of TMS pulses are distinguishable from voluntary activity ([Christensen et al. 2010](#)).

The main objective for developing these procedures in relation to the bodily sense of agency studies is that they allow for almost comparable situations where the ability to make self-other distinctions are important. Common to all three types of experimental procedures is that they rely on movement behaviours where the movement is simple, but the task is relatively difficult and introduces errors in behaviour that can lead to ambiguous situations where the participant can be in doubt as to whether a voluntary movement or externally induced movement is made. The procedures involve tasks that are objective in the sense that voluntary vs involuntary can be measured objectively. Furthermore, the procedures are transparent in the sense that participants can easily understand what it means to distinguish between voluntary or involuntary movements and what it means to answer correctly on a single trial.

Bodily + phenomenal character sense of agency

Only few studies purport to investigate directly the phenomenal sense of agency associated with voluntary bodily movements. We classify the existing studies by whether they use introspective or implicit measures.

First, consider neuroscientific evidence for the claim that the performance of movements is associated with a distinctive experience of activity. A small body of experimental literature suggests that there is a type of phenomenal feeling related to movement. These studies have used either direct electrical cortical stimulation during surgery in tumour or epilepsy patients ([Fried et al. 1991](#); [Desmurget et al., 2009](#); [Fornia et al., 2020](#)) or indirect cortical stimulation in healthy participants using TMS to induce experiences of movement without accompanying movements of the body ([Amassian et al. 1989](#); [Christensen et al., 2010](#)). These experiments indicate that participants either experience a sensation of movement or they experience an urge to move a body part akin to a voluntary experience of moving a body part. In addition, it has previously been shown that participants can discriminate between the experience of motor commands, on the one hand, and somatosensory and proprioceptive feedback, on the other hand ([McCloskey et al., 1983](#)) during a voluntary movement. It remains unclear how to understand these experiences and introspective reports. As in the discussions of the Libet paradigm, it remains unclear what participants are actually reporting (for a recent review of the problems with the Libet paradigm, see [Brass et al. 2019](#)).

Second, sensory attenuation is often taken as an implicit measure of the phenomenal sense of agency related to movement. In sensory attenuation experiments, the sensory consequences of a movement are diminished when the movement is

voluntarily performed. This link to voluntary movement has motivated the use of sensory attenuation as an implicit measure of the sense of agency. The sensory attenuation phenomenon has been shown in humans with tickling sensations ([Blakemore et al. 1998, 2000](#)) and force escalation ([Shergill et al. 2003](#)). For a number of reasons, the use of sensory attenuation to study the sense of agency is problematic. The basic problem is that it remains unknown what exactly is measured by measuring sensory attenuation.

Mechanisms for sensory attenuation were first introduced into the physiological literature to explain how an organism is able to distinguish between retinal changes caused by changes in the world or by movements of the eye ([Sperry 1950](#)). One early explanation of this ability was the assumption of a comparator mechanism. Only by the later theoretical assumption that the comparator mechanisms might explain the sense of agency (for instance, [Frith 2015](#); [Daprati et al. 1997](#); [Haggard 2005](#)—for a historical review of comparator models, see [Christensen and Grünbaum 2018](#)) has the link between sensory attenuation and sense of agency been proposed. As long as the link between comparator mechanisms and a sense of agency is unclear, the link between sensory attenuation and a sense of agency remains equally unclear. It is very likely that sensory attenuation is much broader physiological principle, as the early models of eye movement suggested.

It is worth noting that sensory attenuation procedures differ with respect to their possible constructs—that is, with respect to which attribute they target. Whereas the procedure used by [Blakemore et al. \(1998\)](#) is more in line with the bodily sense of agency (prediction of tactile sensation), the procedure employed by [Timm et al. \(2016\)](#) would be more easily aligned with the external sense of agency (prediction of auditory event). That is, if these attenuation procedures could be said to target a sense of agency in the first place.

These uncertainties might be the reason why the few existing attempts to find correlations between sense of agency judgments (in the external sense) and sensory attenuation [for example, operationalized as N1 and P2 suppression measured by electroencephalography, [Gentsch and Schütz-Bosbach 2011](#)] have been disappointing ([Dewey and Knoblich 2014](#); [Timm et al. 2016](#)). One reason for these missing correlations might be that sensory attenuation does not depend on the self-aspect of a motor action generating an event but captures the predictability of these events irrespective of whether these are self-generated ([Kaiser and Schütz-Bosbach 2018](#)). Consequently, even if researchers were to find some positive relation between the two measures (i.e. explicit or implicit judgements and sensory attenuation), it might be the case that the participants can correctly answer the question of whether they produced the effect, on the basis of a general predictive ability, rather than because of a dedicated sense of agency signal.

Interim conclusions

Most of the above-mentioned studies employ an experimental approach where a movement elicits an external event. In some cases, this event resembles a delayed version of the actual movement performed using a delayed video signal (feedback manipulation), in other cases, the event is a planned auditory event (action-effect manipulation). These studies assume an external conception of the sense of agency. They manipulate the agent's ability to recognize planned environmental events as self-produced or the agent's degree of sense of control over such events. Consequently, these designs confound the bodily

and external constructs of sense of agency. That is, also on trials where participants report a diminished sense of agency for the external event, the participants are actively moving their hands to press a button and should be expected to have a bodily sense of agency for the movement. In conclusion, these experimental paradigms cannot study the bodily sense of agency for movements in absence of their external consequences.

If this brief review of the standard experimental procedures for the study of the sense of agency gives us an adequate and representative picture of the field, then experimental sense of agency research is confronted with a problem. The vast majority of experimental paradigms study either the external sense of agency or they study sensory attenuation or intentional binding. Given the absence of correlations between the implicit and the explicit measures of agency, it remains unclear what the implicit measures are really measuring.

Measuring the Phenomenal Character of the Sense of Agency

We have distinguished between ability and phenomenal character forms of the sense of agency in terms of whether studies use accuracy or introspective scales as a measure. We now discuss an important methodological challenge to the use of subjective measures of the phenomenal sense of agency. The challenge is twofold. First, subjective ratings scales for the sense of agency are difficult to relate to an objectively controlled stimulus condition. This makes it difficult to interpret the different steps or degrees of a subjective scale. Second, given the absence of an unambiguous relation to an externally controlled stimulus and an accuracy score, it becomes difficult for a participant to interpret the experimental task. Our claim is that only if researchers are able to address and overcome the two challenges can we be confident that procedures designed to measure the phenomenal sense of agency really do measure this construct.

Objectivity of agency measures

The interpretation of experimental results depends on the internal validity of the experimental set-up. This in turn depends on the experimenter's ability to control for all relevant confounding factors—that is, extraneous factors that might influence the dependent variable. Trivial as it may sound, this is particularly important when we are trying to measure the strength of some internal signal by introspective reports. The success of psychophysics largely depends on the possibility of relating introspective judgements of the strength of an internal signal (e.g. experienced weight) to the objective physical strength of the stimulus (e.g. the actual weight). Subjective measures in the perceptual domain can usually be related in this way to objective features of the stimulus. This enables an unambiguous interpretation of the subjective measurement scale and allows researchers to control for other sources for the judgement of the participant.

The action domain is different in the sense that the relevant internal signals cannot be related in any straightforward way to physical features of some external stimulus. Irrespective of one's favourite definition of voluntary movement, voluntary actions are driven by internal signals or representations. The organism's behaviour is driven by internal goal representations or motor commands computed on the basis of such representations—even in cases where the organism is voluntarily setting itself up to react quickly to external cues. Relating a

phenomenal sense of agency to some external stimulus condition will therefore be a question of relating an internally generated signal to an external physical condition.

In the case of voluntary movement, features of the internal signal are not related to features of a physical stimulus situation in the same way that strength of the internal signal is related to strength of a physical signal in the perceptual domain. Various manipulations of delays, dislocation, and noise and jittering do not relate to judgement of strength of the phenomenal sense of agency in any unambiguous way that would allow researchers to compute relations in the action domain equivalent to Weber's law in the perceptual domain (see [Dong et al. 2015](#)).

Consequently, if the sense of agency is crucially related to the internally generated representations, then, independently of one's explanatory model of the sense of agency, the strength of the sense of agency cannot be related in a straightforward way to an external stimulus feature. Without an unambiguous relation to some objectively controlled stimulus condition, it remains unclear what different degrees on the subjective agency scale means for an individual participant and for different participants. This makes it difficult to interpret and validate measurement scales for the strength of the phenomenal sense of agency.

Transparency of agency task

If the crucial dependent variable in sense of agency studies is the subjective measure of the strength of a participant's phenomenal sense of agency, then it becomes important how transparent the task is to the participant. By this, we mean that the point of the experimental task and the participants' understanding of what they are supposed to do becomes central. A number of factors conspire to make introspective sense of agency tasks opaque for participants.

First, given that the sense of agency is not part of our everyday folk psychological vocabulary ([Grünbaum 2015](#)), like sensation of pain or visual experience, participants would need clear examples in order to know what the experimenter is talking about. Second, given the absence of an unambiguous relation to objective stimulus conditions, it is very difficult for the experimenter to give clear examples illustrating the degrees of the sense of agency and control that they are experienced in the correct way by the participant. Third, given the absence of correct and incorrect responses when it comes to a phenomenal sense of agency, it becomes very difficult to instruct participants in how to perform the task correctly or appropriately. Together these factors produce a lack of experimental transparency for the participants, and it becomes very difficult to rule out that participants are substituting the intended task (which is hard for them to understand, due to the lack of transparency) for some other task with which they find it easier to comply. An easier task might in some cases be to provide a metacognitive assessment of how certain they are that they produced some event.

Take the following case: In the now popular experimental paradigm by [Wenke et al. \(2010\)](#), an action effect (circle of a specific colour) is objectively determined by the participant's action (left or right key) and events preceding the action (a cue telling the participant which action to make or a free choice cue and a subliminal prime congruent or incongruent with respect to the selected action). The participant has an actual but limited control over the action effects: For each action, there is a distinct set of possible colour effects, although the specific colour is co-determined by the identity of the subliminal prime, which is

random with respect to the action and inaccessible to the participants. In this paradigm, participants are asked to assess their internal phenomenal sense of control over each colour by using a 100-point scale ranging from 'no control' to 'complete control'.

From the perspective of the participants, this is a highly unusual and opaque task. The ratings in the original study by [Wenke et al. \(2010\)](#) are all close to 50 (which might indicate that participants use the scale to answer 'I don't know' or 'I can't judge'). The results show that the ratings are higher when the action is not instructed but up to the participant by a relatively small effect of only ca. 5 rating-scale points (on a 100-point scale). However, the ratings are influenced by the (probably) subliminal action primes, such that when the performed action is congruent with the prime, the rating is slightly higher. The effect is small in absolute numbers (mean control rating of ca. 50 for compatible and ca. 48 for incompatible prime-action conditions).

Given the lack of transparency of the task, the effect can be interpreted in several ways. One interpretation could be that the action primes led to more effortless action selection and the smoothness of the action was behind the slightly different control ratings. This was probably not reflected consciously, because the authors asked the participants and none of them reported having based their ratings on processing fluency, but rather on perceived differences in colour frequencies. Another interpretation could be that the action priming led to an illusion of frequency differences, and this was subsequently used to produce the control ratings, or vice versa, that the priming really led to different sense of action smoothness and this led to the colour frequency illusion. Alternatively, a third interpretation could be that people might have been rating perceived affective valence caused by the increased fluency, so that their rating would not mean 'I feel like a free agent' but rather 'this feels nice' (see [Grünbaum 2015](#) for discussion). Overall, since there was no apparent objective basis for the participants' report of a feeling of control over a colour patch, we cannot rule out that the participants substitute the given task for one they can more easily answer. It is hard to say what exactly the participants were rating.

Interim conclusion

The moral is this. If the experimental paradigm uses a task for which there is no objective stimulus control and performance measure (for instance, in terms of correct or incorrect trials), it means that performance becomes very hard to interpret. It becomes difficult for the participants to understand the task. In the absence of an unambiguous relation of the phenomenal sense of agency to an objectively controlled stimulus condition, we cannot know whether introspective reports across trials and across participants mean the same. In the absence of an objective performance measure, participants cannot be provided with feedback on how well they perform the task. This sense of opacity is exacerbated if the task is highly unusual, such as the introspective rating task in the [Wenke et al. \(2010\)](#) study. If the experimenters have no objective way to interpret the subjective measure and participants are substituting the intended task for some other task, then there will be no way to rule out that the experimental design is measuring some irrelevant attribute. Accepting these considerations, we believe that researchers ought to focus their research effort on studying the sense of agency in the ability sense.

Construct Validity

Let us end by discussing the epistemic consequences of the situation where researchers take themselves to be investigating a single and unified construct of sense of agency but where the experimental procedures might in fact be manipulating and measuring several distinct constructs. The lack of correlations of results from various experimental sense of agency procedures indicates that these constructs might be relatively independent of each other. This unacknowledged theoretical ambiguity of the notion of sense of agency creates a situation where the experimental procedures used in sense of agency studies have low construct validity.

The notion of construct validity is most familiar in the field of psychological testing. In modern test theory, 'a test score is valid to the extent that it measures the attribute of the respondents that it is employed to measure, in the population(s) in which it is used' ([McDonald 2013](#), 133). This problem of whether a psychological measure is really measuring the phenomenon referred to by the psychological theory is not exclusive to psychometric testing. Construct validity is generally accepted as a problem in all areas of scientific psychology, including experimental psychology ([Brewer 2000](#); [Shadish et al. 2002](#)).

Construct validity concerns the degree to which a set of procedures, results obtained using the procedures, and background theories warrant the conclusion that a given procedure is really investigating the psychological attributes (traits, abilities or processes) identified by the psychological theory. The focus in this section is the construct validity of experimental procedures (we use the term 'procedure' to cover things such as experimental design, treatment and measurement). This can be understood as a question about, on the one hand, whether the experimental manipulation really is manipulating the psychological attributes identified by the theory, and, on the other hand, whether the dependent measure really is tracking the changes induced to the attributes identified by the theory. A low degree of construct validity of an experimental procedure means that we cannot know whether the behavioural results are caused by the manipulation of the psychological attribute, we are trying to investigate.

It is a standard psychometric assumption that two types of evidence are necessary to assess the construct validity of a target procedure ([Campbell and Fiske 1959](#); [Strauss and Smith 2009](#)). First, it is necessary to establish that outcomes obtained using the target procedure correlate with outcomes obtained using independent procedures when the various procedures have been designed to manipulate and measure the same or closely related attributes. Consequently, so-called 'convergent validity' and 'criterion validity' serve as evidence for construct validity ([McDonald 2013](#), 133). Second, the target procedure should be significantly less correlated with outcomes of procedures that are assumed to manipulate and measure unrelated psychological attributes. In other words, construct validation of a target procedure requires a contrast between, on the hand, the 'convergent' correlational patterns obtaining between the target procedure and alternative procedures designed to test the same or related attributes and, on the other hand, the 'discriminant' correlational patterns obtaining between the target procedure and procedures designed to test unrelated attributes ([Campbell and Fiske 1959](#)).

It should be emphasized that caution is needed when using psychometric correlational methods in the context of experimental psychology. As it has been pointed out by several researchers ([Hedge et al. 2018](#)), whereas psychometric measures

are usually employed to measure individual differences (psychologists would usually be interested in establishing reliable between-subject variance), experimental procedures are usually employed to estimate typical effects across a population (psychologists would usually be interested in establishing reliable within-subject variance). It remains an open question how to relate these two forms of reliability (Cronbach 1957; Borsboom et al. 2009).

Abstracting from the thorny question of how to use equivalents of psychometric correlational methods in the construct validation of experimental procedures, we will understand construct validation of experimental procedures as conceptual replication: a test of a hypothesis with a given procedure or an effect demonstrated using a given procedure repeated using different procedures (Schmidt 2009, 91). Of particular importance for such a comparison would be how the relation between independent and dependent variables correlates with the relation between variables in the conceptually equivalent procedures. This kind of correlational comparisons often requires that it is possible to establish trial-by-trial comparisons.

It is important to notice that construct validation has a holistic nature. Correlational patterns between the results obtained by using different procedures serve as evidence for construct validity. However, correlations will serve as evidence for the claim that different procedures are targeting the same psychological attribute only if the procedures are connected in a sufficiently complete and clear theoretical framework (Cronbach and Meehl 1955). Only such a theoretical framework will allow researchers to predict and explain the correlational patterns. We do not have any privileged, theory neutral point of view from which we can assess the degree to which procedures are really manipulating the same or different attributes. All we can do is compare the outcomes of independent procedures, given what our theory tells us the procedures are supposed to be testing. Construct validation works by incrementally and holistically improving both procedures and theory (Alexandrova and Haybron 2016; Tal 2017).

Cognitive neuroscience of the sense of agency is challenged both with respect to the theoretical framework and the correlational pattern. As argued above, researchers do not distinguish between the various possible constructs related to the sense of agency. And, as we discussed, the few correlational studies that exist do not support the claim that independent procedures target the same attribute.

Presently, the dominant computational model used to explain the sense of agency is a multifactorial weighting model (Synofzik et al. 2008; Synofzik 2015; Moore and Fletcher 2012). The model describes the experience of agency as having two levels: A low-level sense of agency and a high-level judgement about one's agency. The low-level sense is largely the outcome of sensorimotor processing, whereas the high-level judgement of agency is the outcome of a cognitive integration of many types of information (of which the low-level sense of agency is just one).

Proponents of the multifactorial model often presuppose that various procedures manipulate and measure a common attribute, i.e., the sense of agency. If low-level sense of agency serves as an input to high-level sense of agency, then holding everything else constant we should expect measures of low-level sense of agency (e.g. intentional binding and sensory attenuation) to be significantly correlated with measures of high-level sense of agency (e.g. explicit judgements of control). Consequently, the prediction of the multifactorial weighting model is that at least some of the

various measures should be highly correlated with each other (Beck et al. 2017).

Only few studies have explicitly attempted to correlate explicit and implicit measures of agency in order to determine whether the two measures measure the same underlying phenomenon. Given our discussion above of some of these studies, let us here just mention one study. In Dewey and Knoblich's study (2014), participants performed a key press which caused a tone after a regular interval. A sensory attenuation judgement task (implicit measure of sense of agency) was performed, where participants had to judge whether the tone was louder than a reference tone. Following the sensory attenuation task, participants had to make an explicit agency judgement on a 9-point scale on how much they felt they produced the tones. Dewey and Knoblich (2014) found no correlation between the implicit measure of sensory attenuation and the explicit agency judgements. One problem with this correlational study is that it does not allow for a trial-by-trial comparisons of outcomes of the different procedures. The procedures only allowed participants to give sense of agency ratings after a completed block of trials.

The results of more recent studies are mixed. In particular, a high-powered study by Schwarz et al. (2019) find no correlation between implicit and explicit measures of sense of agency, whereas Imaizumi and Tanno (2019) claimed to find trial-by-trial correlations between binding measures and explicit agency ratings for key press-tone experiments. Unfortunately, it cannot be ruled out that Imaizumi and Tanno's (2019) correlation is an example of Simpson's paradox (Simpson 1951), where, when combined from multiple action-effect tasks at different delays, a series of non-correlating measurements between implicit and explicit measures of agency reveal a significant correlation between implicit and explicit measures.

The relationship between intentional binding and other implicit measures, such as sensory attenuation, is also telling. Dewey and Knoblich (2014) compared sensory attenuation and binding and found no relation between sensory attenuation and bindings, suggestion that these two procedures measure different things. Recently, also Borhani et al. (2017) were unable to find any significant relation. The relationship between the two measures is complicated, to say the least. Some studies (Schwarz et al. 2018b) have found no visual sensory attenuation effect in highly trained action-effect relations, suggesting that it is not a universal phenomenon, but other studies (Kilteni et al. 2019) have shown that different delays and related attenuation effects were very adaptive. Given our two-by-two conceptual distinction, it is not clear that these implicit procedures are manipulating and measuring the same construct. Sensory attenuation procedures sometimes manipulate properties of the movement (Blakemore et al. 1998) and sometimes action-effects (Gentsch and Schütz-Bosbach 2011).

In absence of the predicted correlations between the various measures of the sense of agency, the epistemic situation is muddled. There are several possible explanations of the lack of expected correlational patterns. Let us here mention four. We are not presuming that this list of possible explanations is exhaustive.

First, as already indicated, one explanation might be that whereas psychometric correlational construct validation would normally work by looking for similarities in between-subject variance, experimental procedures would normally gauge within-subject variance. Making progress with the construct validation of experimental procedures in the study of sense of agency requires the development of paradigms that enable

fine-grained comparisons of between-trial variance. In the absence of such comparisons, the lack of correlations between effects of various procedures is hardly evidence of anything.

Second, a cue-integration model could insist that different cues might be weighted differently. For instance, cues for goal-completion might be weighted such that if the goal is completed, the agent will express a sense of agency even if the perception-motor control is diminished (Kumar and Srinivasan 2014). The result might be that procedures gauging these different components would lack significant correlation. In response, it is important to remember that correlations or lack of correlations is not important on their own. They become important in the context of a theory according to which certain correlational patterns are or are not to be expected. Given one version of the comparator model of motor control and sense of agency, we would expect the effect of sensory attenuation to be correlated with the effect of intentional binding (since both effects are explained by the same predictive mechanism). Furthermore, given reasonable assumptions about these implicit measures and cues used for action-recognition, we should expect intentional binding to be related to explicit judgements of agency.

Third, the lack of expected correlational patterns should be explained by faulty or noisy experimental procedures. We do not find what we seek because our experimental procedures are sub-optimal. And finally, fourth, the lack of expected correlational patterns between implicit sense of agency procedures and between implicit and explicit procedures is evidence that these procedures are not manipulating and measuring a common, single attribute.

Our claim is that simply producing more data with refined versions of old procedures will provide only little help with clearing up this epistemically ambiguous situation. One important aspect of this problem is the fact that dominant theories of the sense of agency are conceptually patchy and ambiguous so long as they do not acknowledge the four possible senses of agency.

The consequence is low construct validity for many senses of agency studies. Rather than targeting a common attribute, the various procedures used to study the sense of agency might manipulate and measure different kinds of attributes and processes. Some procedures might measure an ability, whereas others might measure the phenomenal strength of an experience. Furthermore, some procedures might target a bodily sense of agency, whereas others might target an external sense. We have no reason for thinking that these are aspects of one common construct and that the various procedures measure a common attribute. In fact, the few correlational studies that exist could be suggesting otherwise (Dewey and Knoblich 2014; Saito et al. 2015; Schwarz et al. 2019; Wen 2019).

Concluding Remarks

We have argued that we should acknowledge conceptual distinctions between ability vs phenomenal character and bodily vs external forms of sense of agency. This gives us four possible constructs. Furthermore, we argued that the conceptual distinctions are mirrored by distinctions between types of experimental paradigms. The sense of agency as an ability is typically studied by action-recognition paradigms using accuracy as a measure, whereas the phenomenal sense of agency is typically studied using either introspective reports or implicit measures. The external sense of agency is typically studied in paradigms manipulating an external event, whereas the bodily sense of agency is studied by manipulating the self-other initiation of

the bodily movement. We argued that the majority of experiments use some procedure that manipulates the external sense of agency. Lastly, we went on to argue that due to their lack of objectivity and transparency, it is hard to determine what paradigms using subjective measures of phenomenal sense of agency are really measuring.

One important reason for thinking that these different kinds of experimental procedures are tracking different kinds of constructs is the absence of correlations. Results obtained using the procedure of sensory attenuation are not correlated with results obtained using the intentional binding procedure (Dewey and Knoblich 2014; Borhani et al. 2017). And results using implicit measures are not correlated with results obtained using explicit measures (Schwarz et al. 2019). To be sure, this absence of correlational evidence might just only be that: an absence of evidence.

Summing up, we have provided reasons for accepting that a majority of procedures target either an external ability sense of agency or not a sense of agency at all. Without a clear picture of which construct a given experimental procedure is manipulating and measuring, it remains impossible to test the various competing computational models of the sense of agency.

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