

When self-prioritization crosses the senses: Crossmodal self-prioritization demonstrated between vision and touch

Sarah Schäfer^{1*} , Ann-Katrin Wesslein², Charles Spence³ and Christian Frings¹

¹University of Trier, Germany

²Eberhard Karls University, Tübingen, Germany

³University of Oxford, UK

The investigation of self-prioritization via a simple matching paradigm represents a new way of enhancing our knowledge about the processing of self-relevant content and also increases our understanding of the self-concept itself. By associating formerly neutral material with the self, and assessing the resulting prioritization of these newly formed self-associations, conclusions can be drawn concerning the effects of self-relevance without the burden of highly overlearned materials such as one's own name. This approach was used to gain further insights into the structure and complexity of self-associations: a *tactile* pattern was associated with the self and thereafter, the prioritization of the exact same *visual* pattern was assessed – enabling the investigation of crossmodal self-associations. The results demonstrate a prioritization of self-associated material that rapidly extends beyond the borders of a sensory modality in which it was first established.

Imagine yourself at a noisy cocktail party. Suddenly someone behind you mentions your name: Despite your best efforts, your attention will likely switch from whoever you were talking to, and onto the voice of the person who just uttered your name. In the sense of this prominent cocktail-party phenomenon (Moray, 1959), self-relevant stimuli, such as your own name, are preferentially processed, even though the semantic characteristics of other stimuli are typically not encoded or recalled. Many similar findings have subsequently supported this assumption (e.g. Conway, Cowan, & Bunting, 2001; Wood & Cowan, 1995) and extended it to other sensory modalities (e.g. Keyes & Brady, 2010; Shapiro, Caldwell, & Sorensen, 1997). Yet, the question was raised as to whether the reported effects of the participant's own name, or a picture of their face, might also be simply explained by stimulus familiarity. One could, for example, argue that these stimuli are highly overlearned and much more familiar in comparison with the non-self-relevant stimuli (i.e. a stranger's name or face) that are typically used as controls. The potential

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*Correspondence should be addressed to Sarah Schäfer, Department of Cognitive Psychology and Statistics, University of Trier, D-54286 Trier, Germany (email: schaefer@uni-trier.de).

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confound associated with such studies has been addressed by the introduction of the matching paradigm in which a presumably neutral stimulus (such as an arbitrarily chosen shape) is assigned to the participant and a second stimulus to an irrelevant other. In a subsequent matching task, participants show a robust prioritization of the newly formed self-association – a self-prioritization effect (SPE; Sui, He, & Humphreys, 2012). Hence, even without highly overlearned familiar stimuli in the self-relevant condition, a difference in the processing of self-relevant content and non-self-relevant content can still be reliably obtained (e.g. see Constable, Elekes, Sebanz, & Knoblich, 2019; Humphreys & Sui, 2016; Schäfer, Wesslein, Spence, Wentura, & Frings, 2016).

However, despite a wide range of articles concerning the SPE having been published to date, the processes underlying the SPE in the matching paradigm are still being debated. For example, one approach to understanding the SPE has been to investigate the level at which these self-associations affect stimulus processing. Researchers in early publications supposed that it might be caused by a perceptual advantage of the self-associated stimuli as compared to the other-associated stimuli (Sui et al., 2012; Sui, Liu, Mevorach, & Humphreys, 2015). In line with such a suggestion, Macrae and colleagues (2017) demonstrated an advantage of self-associated trials in a task that used braking continuous-flash suppression (bCFS; but see Stein, Siebold, & Zoest, 2016). The bCFS approach is typically used to investigate prioritized access to visual awareness. Additionally, a recent study has suggested that the SPE is located at a later, post-perceptual stage of information processing (Janczyk, Humphreys, & Sui, 2019). Other studies have, though, challenged the perceptual account in favour of a memory advantage (Reuther & Chakravarthi, 2017) or else a learning (Fuentes, Sui, Estévez, & Humphreys, 2016) or association advantage (Schäfer, Wentura, & Frings, 2020; Sui & Humphreys, 2015) due to the self-relevance of the stimuli instead.

In line with the assumption that self-relevance influences stimulus processing not just at the perceptual level, but at multiple levels (for a theoretical review, see Sui, 2016), the self-associated stimulus seems to be represented at a post-perceptual level of information processing. In that regard, one study tested the prioritization of stimuli that only shared the semantic concept with the stimulus that had been associated with the self. More specifically, after the written instruction that, for example, a piano shall be associated with the self, a prioritization of the self with various pictures of the piano and associated sounds was tested (Schäfer, Wentura, & Frings, 2015). The results revealed a prioritization with any stimulus that was related to the semantic concept. Thus, the question arises as to whether the self-concept, comprising a network of semantic concepts, is represented at a post-perceptual level or not.

To put the assumption of a ‘higher-order self-network’ – in terms of a representation based at a post-perceptual level – to the proverbial test, in the current study, we investigated whether the newly formed self-associations are restricted to the sensory modality in which they were learned or whether instead they generalize to another sensory modality. Building on Schäfer et al.’s (2015) study, which suggests that self-associations can be generalized, in the current research, this generalization is put to a further test by switching the sensory modality. We used the standard procedure of the matching paradigm with a slight modification: We presented tactile stimuli in the association phase and the exact same visual patterns in the matching task. In other words, we associated one tactile stimulus to the self (and other tactile stimuli to non-self-relevant others) and tested for the prioritization of a visual equivalent of this tactile stimulus. Note that temporal patterns or rhythms can simply be described in terms of a sequence of ‘signal present’ and ‘signal absent’ events that vary only with respect to their time-course,

so that exactly the same stimulus information (i.e. the temporal pattern) could be presented to several of the participant's senses (see also Frings & Spence, 2010). If a prioritization of the visual stimulus is found after tactile stimuli had been associated with the self, this would be a strong indication for a post-perceptual, crossmodal representation of self-associations.

Importantly, we chose tactile stimuli to be associated with the self because the sense of touch plays a key role in self-perception and helps to distinguish the self from the surroundings (Ehrsson, Spence, & Passingham, 2004; Gallace & Spence, 2014; Martin, 1995). Additionally, we know about the multisensory representation of the space directly surrounding the body (for a review, see Holmes & Spence, 2004; for the association of tactile stimuli with the self, see Schäfer, Wesslein, et al., 2016; Schäfer, Wentura, Pauly, & Frings, 2019), so that we assumed that the largest crossmodal effects might well be observed when applying the to-be-associated stimuli directly to the body surface itself. Taken together, we hypothesize the self-network to be an amodal construct, which would be indicated by a significant SPE with visual stimuli even though tactile stimuli have been associated with the self (provided, of course, that the visual stimuli depict equivalents of the tactile stimuli).

Method

Participants

Thirty-four students from a German university (23 female) took part in the experiment in return for course credit. The data from two of the participants (both female) were discarded prior to analysis because they committed far too many errors, or else responded far too slowly (i.e. far-out values according to Tukey, 1977) resulting in a sample size of $N = 32$. Apart from one participant who did not report their age, the median age was 24 years (ranging from 19 to 32 years) and participants had normal or corrected-to-normal vision. According to power constraints, the SPE that has been documented with visual stimuli has been rather large in previous studies ($d_z > 0.80$; Schäfer, Wesslein, et al., 2016; Sui et al., 2012). Importantly, we assume the SPE in our study to be smaller due to the switch of the modality (Spence, Nicholls, & Driver, 2001). However, with $N = 32$, even an effect of $d_z = 0.45$ would be found with a power of $1 - \beta > .80$ ($\alpha = .05$, one-tailed; calculated with G*Power, Faul, Erdfelder, Lang, & Buchner, 2007).

Procedure

In order to reduce the amount of environmental noise to a minimum, the participants were tested individually in a completely light- and sound-proofed testing chamber. An experimenter provided some initial instructions and then left the room, before the task instructions were presented on the screen. The experiment started with an association phase, in which the to-be-learned associations were shown on the display. Here, for each participant, each of three tactile stimuli, consisting of different onsets and offsets of vibrotactile pulses (see Figure 1), was assigned to one of three labels. The particular associations were presented to the participant by presenting one label on the screen in written form in each trial for 500 ms, followed by the delivery of a single tactile stimulus (i.e. vibrotactile pulse) for 300 ms to the participant's hand while the label remained on the screen and also remained for a further 1,700 ms. After an interstimulus interval of 2,000 ms, the next trial followed. Each stimulus-label association was presented six times. Hence, the association phase comprised 18 trials presented in a random order. The

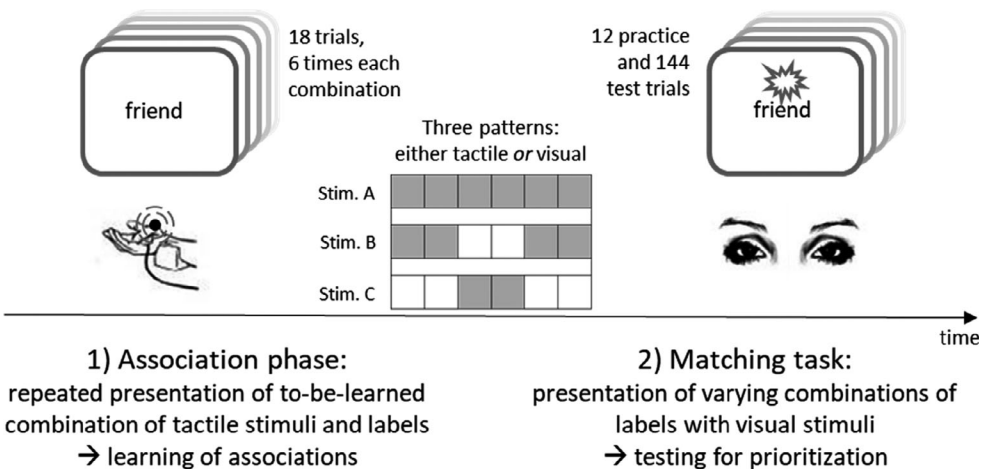


Figure 1. Schematic presentation of the procedure of the experiment demonstrating the switch of modality between the association phase and the matching task. The three visual or tactile patterns consisted of six different signal-on signal-off sequences with signal onset indicated in grey and signal off in white colour in the figure.

participants were instructed to learn these associations – more specifically, associations of labels and vibrotactile pulses presented to their hand – and were informed that they would be asked about them later.

The matching task followed after the association phase. The participant's task was to judge whether each stimulus-label combination that was presented corresponded to one of the initially learned associations or not. Here, the participants were told to place their left index finger on the S-key (non-matching response) and their right index finger on the L-key (matching response). Throughout the experiment, both of their arms were placed on armrests in order to prevent any disturbance because of the tactile stimulus that was delivered to the left hand.

After 12 practice trials, the test phase of the matching task started. In each trial, after a blank slide (500 ms) and a fixation cross (550 ms), a stimulus-label combination was presented. However, this stimulus-label combination contained a label and a flashing visual stimulus which appeared on the screen simultaneously (for a schematic presentation of the stimuli, see Figure 1). The flashing stimulus had a duration of either 100 or 300 ms (see Figure 1), and the label remained on the screen for a maximum of 1,500 ms or until a response had been given. If no response was detected, a blank slide appeared until a response had been registered. Each of the nine possible stimulus-label combinations was presented several times and in a random order, whereby matching combinations were presented twice as often thus giving rise to an equal number of matching and non-matching trials. The test phase consisted of 144 trials, and no feedback was given to prevent further learning. Importantly, before this test phase, the participants were not informed that tactile patterns could switch to visual patterns, thus they had no idea of a potential switch of modality.

Material and apparatus

The experiment was conducted using standard PCs with standard TFT monitors, German QWERTZ keyboards, and E-Prime 2.0 software. The labels were written in Courier New

and presented in white on a black background. The labels were always presented in the middle of the screen to have the greatest consistency between the association phase with tactile stimuli and the matching task with the visual stimuli. Thus, in the association phase, each label was presented in the centre of the screen and each tactile stimulus was presented on the participant's left hand, while in the matching task, the label was presented from the centre of the screen and a flashing stimulus above it (see Figure 1). With a viewing distance of about 50 cm throughout the experiment, the labels subtended 0.7° visual angle vertically. The tactile stimuli used were constructed as follows: a continuous 300-ms pulse as Stimulus A, a sequence of a 100-ms pulse, a 100-ms pause, and a 100-ms pulse as Stimulus B, and a 100-ms pulse as Stimulus C (see Figure 1). The presentation of the tactile stimuli (~ 250 Hz, about $71 \mu\text{m}$ peak-to-peak amplitude) was controlled via a serial interface. That is, the vibrotactile stimuli were delivered by means of a tactor (Model C-2, Engineering Acoustic, Inc.) which was 1.17 cm in diameter and 0.30 cm thick. The visual stimulus was presented as a sequence of light grey squares against a black background (with a visual angle of $2.6^\circ \times 2.6^\circ$) suggesting a flashing stimulus. Importantly, each visual pattern exactly mirrored one of the tactile patterns. Thus, either a continuous 300-ms flash (Stimulus A), a 100-ms flash, 100-ms pause, 100-ms flash sequence (Stimulus B) or a 100-ms flash (Stimulus C) was presented (see Figure 1)¹.

We used the German words *Ich* [I] as the self-relevant label and *Freund* [friend] and *Fremder* [stranger] as the two non-self-relevant labels. The friend label was chosen to have a strong comparison condition for the self-relevant conditions because a friend is a 'close-to-the-self, but not myself' person. The assignments of these labels to the particular vibrotactile pulses, that is the concrete stimulus-label associations, were varied following a Latin-square design. Thus, each label was assigned to each vibrotactile stimulus for one third of the participants.

Design

As typical for the matching paradigm, the experiment comprised a 2 (matching condition: *matching* vs. *non-matching*) \times 3 (association: *self* vs. *friend* vs. *stranger*) repeated-measures experimental design. The factor 'association' thereby represents the association which was given to the tactile stimulus in the association phase although performance was analysed only in those trials where visual stimuli were presented (i.e. in the matching task). Hence, all matching or non-matching trials with one particular visual stimulus (e.g. Stimulus A) were grouped based on the fact that the tactile equivalent was associated with a particular label.

The SPE is defined as better performance in self-associated matching trials as compared to other-associated matching trials (Sui et al., 2012), so that we will test for our hypothesis in the matching condition. Non-matching trials only serve as filler trials to make the matching task a useful task (so that participants have to compare each presented

¹ Note that, before the experiment started, the participants went through a pattern-tone combination task that was completely irrelevant to the current study. In this task, the tactile stimuli were presented on either the participant's left or right hand and were combined with one of two tones. The participants were instructed to indicate the hand on which they perceived the stimulus. To test whether this preceding task had any influence on the pattern of data in the matching task, a 2 (tone condition in pattern-tone combination task: tone 1 vs. tone 2) \times 2 (matching condition: matching vs. non-matching) \times 3 (association: self vs. friend vs. stranger) repeated-measures MANOVA was conducted with 'tone condition in pattern-tone combination task' as a between-participant factor. The analysis did not reveal any influence; we found neither a main effect, $F(1, 30) = 1.14$, $p = .294$, $\eta_p^2 = .04$, nor any interaction effect with this factor, all $F_s < 1$, all $p_s > .474$.

combination to the previously learned combinations). Hence, no hypotheses were formulated in relation to this condition.

Results

Only correct responses with response times (RTs) above 100 ms and below three interquartile ranges above the third quartile of the overall RT distribution (Tukey, 1977) were used for the RT analysis. Averaged across participants, 84.5% of the trials were selected for RT analysis; 14.7% of the trials were excluded because of erroneous responses and 0.8% due to the RT-outlier criteria. Mean RTs and error rates are shown in Table 1.

Response times

A one-factorial (stimulus association: *self* vs. *friend* vs. *stranger*) repeated-measures MANOVA with mean RTs as the dependent variable revealed a significant main effect, $F(2, 30) = 19.07, p < .001, \eta_p^2 = .56$. This indicates that the association had a measurable influence on participants' performance (for the use of MANOVA analysing repeated-measures designs, see O'Brien & Kaiser, 1985). Importantly, within this MANOVA, the first Helmert contrast reflects the comparison of the first association condition (i.e. self-associated) with the average of the other two conditions (i.e. the mean of friend- and stranger-associated). This contrast exactly mirrors the standard formula of the SPE and can therefore directly be used to test for the SPE. Hence, no further post-hoc tests were necessary in order to test the SPE, as the first Helmert contrast was significant, $F(1, 31) = 39.22, p < .001, \eta_p^2 = .56 (d_z = 1.11)$, meaning that responses to trials with the visual stimulus representing the self-associated tactile stimulus were significantly faster than responses to those trials with the visual stimuli representing the other-associated tactile stimuli (see Figure 2). This rather large SPE with tactile stimuli matches previous studies assessing the prioritization of tactile stimuli ($d_z = 6.4$ in Schäfer, Wesslein, et al., 2016). A Bayesian one-sample *t*-test for the SPE revealed a Bayes Factor for the alternative hypothesis (i.e. for the SPE to differ from zero) of $BF_{10} = 28964.9$, indicating 'extreme evidence' for the significance of the SPE (based on the classification scheme for the interpretation of Bayes factors, Jeffreys, 1961; see also Wagenmakers et al., 2018).

Accuracy

Accuracy was analysed computing signal-detection-sensitivity indices (d') for each association condition in order to consider the individual response criterion. Correct

Table 1. RTs in milliseconds and absolute error rates as well as the sensitivity measure d' as a function of stimulus association and matching condition (matching vs. non-matching). Standard deviations are in parentheses

Stimulus association	RTs		Error rates		d'
	Matching	Non-matching	Matching	Non-matching	
Self	814 (128)	898 (136)	2.2 (3.1)	3.3 (3.8)	2.7 (1.1)
Friend	924 (177)	1011 (183)	3.5 (2.7)	4.3 (3.6)	2.1 (0.9)
Stranger	919 (145)	974 (153)	3.5 (2.2)	4.3 (2.8)	2.0 (0.7)

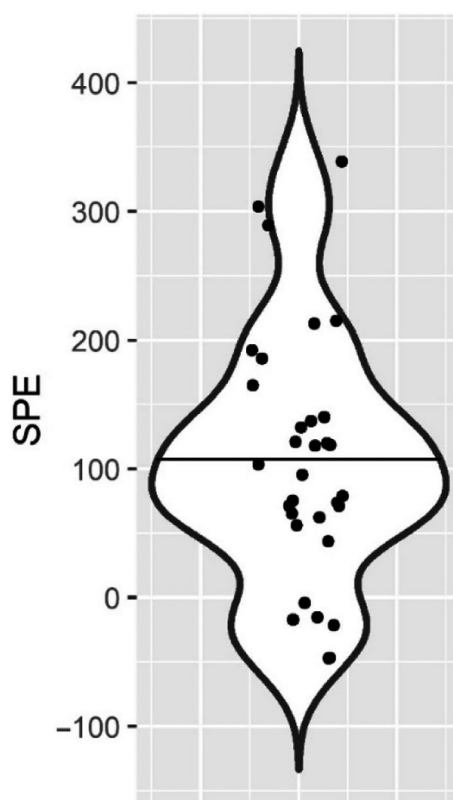


Figure 2. A violin plot depicting the distribution as well as the samples mean (horizontal line) of the SPE in ms: a positive SPE indicates that participants more rapidly confirmed self-relevant matches than non-self-relevant matches.

responses in the matching trials were considered as hits, whereas erroneous responses in non-matching trials were considered as false alarms. We followed the log-linear approach to account for cases with 100% hits or 0% false alarms (see Hautus, 1995; Stanislaw & Todorov, 1999). In accordance with the RT analysis, a one-factorial (stimulus association: *self* vs. *friend* vs. *stranger*) repeated-measures MANOVA with d' as the dependent variable was conducted. This analysis revealed a significant main effect, $F(2, 30) = 12.34$, $p < .001$, $\eta_p^2 = .45$, confirming the effect of the association. As for the RTs, the first Helmert contrast in this analysis was associated with $F(1, 31) = 24.13$, $p < .001$, $\eta_p^2 = .44$ ($d_z = 0.68$), demonstrating a significant SPE in the d' measure, too.

Discussion

We tested the assumption of a higher-order, crossmodal self-network by investigating whether newly formed self-associations are restricted to the sensory modality in which they were initially presented or whether instead they generalize to another sense. The data unambiguously indicated a prioritization in those trials comprising the visual stimulus that represented the self (as opposed to those representing other instances) although this stimulus did not share any *sensory* features with the actual self-associated (tactile)

stimulus that had been presented during the training phase. These results therefore suggest that the SPE occurs crossmodally. That is, the processes contributing to the SPE operate not only at a post-perceptual and *unisensory* stage of information processing (as has been indicated by the prioritization of a semantic concept in Schäfer et al., 2015) but they also seem to operate on what might be termed an *amodal* level. While rhythm has modal features (i.e. modality-specific features such as amplitude for auditory stimuli or colour for visual stimuli) as well as amodal features (i.e. non-modality-specific features such as temporal pattern of on- and off-signal), visual and tactile rhythms or patterns (as those used in our study) can only share amodal features. Hence, while, of course, modal stimulus features (of the tactile stimuli) could have been associated with the self, too, it was the amodal features which led to the SPE – as only those features were shared. Accordingly, the SPE is not only an effect at a post-perceptual stage of information processing (as has been shown before), but it even survives a switch of stimulus modality. One might ask whether this *amodal* representation of the self-associated stimulus is built up automatically whenever a stimulus is associated with the self or whether it was built goal-directed, specifically due to the requirements at hand in our matching task. In the latter case, the crossmodal SPE would have occurred merely because of the particular goal settings in our study. Yet, a goal-directed crossmodal representation of the stimuli is rather unlikely for two reasons. First, participants did not expect a modality switch during the association learning phase of the study. Second, as soon as the information about the modality switch was given (i.e. in the test phase), no further learning was possible because no feedback was provided. Thus, performance in this phase is mainly affected by the retrieval of what has been assigned previously.

What can be concluded from this crossmodal-SPE result is that not only the particular stimulus that arbitrarily happens to be associated with the self, but also related stimuli are handled as self-relevant and therefore prioritized. Thus, amodal features are tagged to the self so that the resulting prioritization is far-reaching. Furthermore, it should be noted that the SPE in the matching paradigm is assumed to depict a very basic component of the self (Humphreys & Sui, 2016; Northoff, 2016; Schäfer & Frings, 2019); it has already been explained as a simple differentiation between self and non-self (Gallagher, 2000; Hommel, 2019) or as a stable anchor between different, more elaborate forms of self-relevance (Sui & Humphreys, 2017). Thus, although obviously very basic (representing a simple classification in self-relevant/non-self-relevant), at the same time this component of the self would appear to be far-reaching. In addition to this, another study suggests that self-prioritization is specific and does not cause the wasteful prioritization of *any* similar stimulus (Schäfer, Frings, Frings, & Wentura, 2016). Integrating these two findings, self-associations would appear to be both specific and also far-reaching. In a broader sense, this suggests that self-associations can be quite general, but they can also be very precise, potentially depending on the requirements of the context. Such a broad definition of the effects of self-relevance including various representations goes in line with the Self-Attention Network which postulates diverse influences of self on attention – top down as well as bottom up (Humphreys & Sui, 2016). Further, it emphasizes the assumption that the way in which stimuli are bound to the self – once they are perceived as being self-relevant – varies as a function of the contextual requirements and is thereby highly functional.

In that regard, the question arises as to which mechanisms contribute to the tagging of crossmodal patterns to the self. Importantly, temporal patterns were task relevant in the current study. Regarding the literature concerning contingent attentional capture, crossmodal stimuli have been shown to capture attention involuntarily if they are task

relevant (e.g. see Mast, Frings, & Spence, 2015) and the task-load is not too high (Spence, 2010). Thus, potentially, the task-relevance of a feature is necessary for self-integration or, contrary to that, also a transfer of task-irrelevant features is possible. The crossmodal representation of the stimuli in our study might be, as already suggested above, the result of the current task (patterns were task relevant) or the current procedure (tactile stimuli in the association phase). Yet, even in clearly amodal tasks with only visual stimuli, self-associations are associated with activation in the left posterior superior temporal sulcus (Sui, Rotshtein, & Humphreys, 2013), a brain area widely considered to be associated with multisensory processing (see, e.g. Beauchamp, Yasar, Frye, & Ro, 2008; Driver & Noesselt, 2008). There is thus reason to presume that it is not merely the task set in our study which caused the crossmodal representation. However, this is undoubtedly an interesting question to be investigated in further research.

What is more, the finding of a crossmodal representation of the tactile stimuli in the association phase fits with the fact that the brain represents those objects that are nearer to, or in contact with, the body in a more thorough, more complex way, and involving more sensory modalities than it represents objects which are located in extrapersonal space (i.e. beyond the space directly surrounding the body; for a review, see Holmes & Spence, 2004). The parallel processing of information from different sensory modalities in the space directly surrounding the body, described as peripersonal space (as it is postulated by previous research, see Holmes & Spence, 2004), appears naturally when considering the fact that objects at a greater distance can be perceived through a limited number of senses, whereas those objects close to the body can impact upon all of our sensory systems (i.e. including gustation and all of the sub-modalities of touch; Holmes & Spence, 2004) – and the results of our study completely go in line with this. Of course, the investigation of a potential unisensory (vs. a more complex, multisensory) representation of self-relevant stimuli in *extrapersonal* space (for the claim that multisensory information is processed differently depending on the region of space in which it is presented, see Van der Stoep, Nijboer, Van der Stigchel, & Spence, 2015) as well as the question whether the multisensory representation of the stimuli in our study is particular to tactile stimuli constitutes a topic for further research. However, the finding of a crossmodal SPE suggests that those stimuli that happen to be presented in *peripersonal* space are represented crossmodally and this leads to a further interesting question: Why should stimuli in the peripersonal space be represented in a more thorough, crossmodal way? One answer might be an *a priori* bias to consider things in peripersonal space as self-relevant whereas those things situated in extrapersonal space are assumed to be less self-relevant. Thus, the simple *a priori* categorization of stimuli as self-relevant might cause a crossmodal representation of it. Considering the number of problems the integration of features from different sensory modalities faces (for a recent review, see Spence & Frings, 2020), the crossmodal representation of stimuli simply because of the categorization of those stimuli – which is, of course, only a first suggestion after this initial finding – as self-relevant suggests a strong effect of self-relevance.

Taken together, the results reveal further evidence for the assumption that the associations that our basic self-concept consists of, are both complex – including semantic concepts as well as crossmodal information – and that the resulting prioritization is far-reaching. What is fascinating is that more and more evidence is generated to suggest that these self-associations are highly functional.

Author contributions

Sarah Schafer (Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Validation; Visualization; Writing – original draft; Writing – review & editing) Ann-Katrin Wesslein (Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Validation; Visualization; Writing – original draft; Writing – review & editing) Charles Spence (Conceptualization; Supervision; Visualization; Writing – original draft; Writing – review & editing) Christian Frings (Conceptualization; Formal analysis; Funding acquisition; Project administration; Resources; Software; Supervision; Visualization; Writing – original draft; Writing – review & editing).

Conflicts of interest

All authors declare no conflict of interest.

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Data availability statement

The data that support the findings of this study will be openly available in PsychArchives, a disciplinary repository for psychological science at <http://dx.doi.org/10.23668/psycharchives.4359> (doi for raw data) and <http://dx.doi.org/10.23668/psycharchives.4358> (doi for code to raw data).

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