**Why the self stands out: The left posterior parietal cortex responds to social-salience after self-conditioning**

Jie Sui[1, 2], Minghui Liu[3], Carmel Mevorach[4]and Glyn W. Humphreys[2]

Affiliations:

[1]Department of Psychology and Center for Biomedical Imaging Research, Biomedical Engineering Department, School of Medicine, Tsinghua University,

Beijing, 100084, China

[2]Department of Experimental Psychology, University of Oxford,

Oxford, OX1 3UD, UK

[3]Department of Psychology, Northeast Normal University,

Chuangchun, 130024, China

[4]School of Psychology, University of Birmingham,

Birmingham B15 2TT, UK

Correspondence to: Jie Sui: jie.sui@gmail.com, +44(0)1865 618638 or Glyn W. Humphreys: glyn.humphreys@psy.ox.ac.uk, +44(0)1865 271356, who contributed equally to this work in terms of experimental design and writing up the paper.

**Abstract**

Perceptual learning is associated with experience-based changes in stimulus salience. Here we use a novel self-conditioning method to show that learning an association between a self-label and a neutral stimulus produces fast alterations in social salience and this modulates visual selection. Participants associated neutral shapes with either themselves or a friend, over a short run of training trials. Subsequently the shapes had to be identified in hierarchical (global-local) forms.The data show that conditioning a stimulus to the self had effects on visual selection equivalent to altering perceptual salience. Similar to previously observed effects linked to when perceptually salient distractors are ignored, effects of a self-conditioned distractor also increased activation in the left posterior parietal cortex. The results show that self-conditioning to sensory stimuli rapidly modulates saliency-based neural responses, consistent with social context affecting how we perceive the world. The self-conditioning procedure provides a new way to understand how personal significance affects perception.

Human perception is subject to incremental learning through repeated exposure, which gradually changes the perceptual salience of behaviorally relevant stimuli. Changes in salience through experience-based perceptual learning have standardly been reported after several hours of practice (e.g., Karni and Sagi 1993; Li et al. 2009; Watanabe et al. 2001), perhaps linked to neurochemical changes in the brain. What happens, however, if we make a social rather than a perceptual association to a stimulus – as when we associate a stimulus to ourselves rather than to other people? Do such social associations mimic changes in perceptual salience, and are effects of social and perceptual salience modulated by common brain mechanisms?

We have recently shown that there can be rapid behavioral changes in the response to neutral stimuli which are associated with ourselves rather than another person (Sui et al. 2012). We had participants learn an association between a geometric shape and label referring either to themselves, their best friend or a stranger. Subsequently participants were presented with the shape and a label and had to verify that the stimuli were paired correctly (the original shape-label pairings) or whether they were re-paired (e.g., the prior 'self' shape was presented with the label for the best friend). Response times and accuracy were greatly benefitted for matching shape-label pairs for the self compared to the best fried and stranger. The self-bias robustly occurred in different contexts and with contrasting task demands. In addition, self matching pairs showed weaker effects of contrast reduction compared to the other pairings, suggesting that there was enhanced perceptual processing for self-associated stimuli. Similar effects were found with stimuli associated with high relative to low reward, suggesting that the self-association effect might reflect differential reward values linked to the self compared with other people (Sui et al. 2012). We have also recently shown that this self-advantage in behavior is supported by a neural circuit involving the ventral medial prefrontal cortex (vmPFC) and the left posterior part of the superior temporal cortex (LpSTS).

The coupling within this circuit increases for self-related stimuli compared with stimuli related to other people consistent with self-related representations in the vmPFC being linked to social attentional responses operating within the LpSTS (Sui et al. 2013). This evidence indicates that neutral stimuli (geometric shapes, in this instance) are able to rapidly acquire social salience by being associated with the self rather than with other people. However, it is unknown whether the arbitrarily learned social salience of a stimulus can modulate visual selection, and, if it does, whether the effects are similar to the effects of perceptual salience on selection. This was examined here. Participants were asked to select target shapes in hierarchical forms, with the shapes either having high or low social salience by dint of their being associated with the self or with another person. Previous work on perceptual salience has focused on the functional and neural processes involved when we ignore perceptually salient distractors (Mevorach et al. 2006). We ask whether equivalent effects arise when social rather than perceptual saliency is manipulated, and salient self-related distractors have to be ignored.

Previous work on perceptual saliency has used a global/local task and hierarchical stimuli. In these experiments global forms are made more salient by blurring the local elements, while using high contrast local elements differing in color increases the relative saliency of local forms (Mevorach et al. 2006, 2009, 2010). Responses to targets with low perceptual salience are disrupted by the presence of a distractor at the other level that has high perceptual salience, and the effect indicates that visual selection is modulated by the salience of stimuli and not simply by the level of the target within the hierarchical figure (though often there are also prioritized responses to targets occurring on the global relative to the local level, e.g., Navon, 1977). In particular, the selection of low salient targets is correlated with increased activation in the left intraparietal sulcus (IPS). Functionally the activity in the left IPS is associated with suppressing neural activity in the left occipital pole

which would otherwise respond to high saliency distractors (Mevorach et al. 2010). In the current study, we combined (i) self-conditioning (Sui et al. 2012, 2013) to induce social salience and (ii) a hierarchical visual recognition task to mimic the manipulations previously made to alter perceptual saliency (Mevorach et al. 2006, 2009, 2010). We asked whether functional and neural effects equivalent to those produced by perceptual changes can be introduced simply by making a self-related association to a stimulus – is there an effect of 'socially salient' distractors, induced by self-association?

We conducted four experiments. First (Experiment 1) we carried out a baseline study to establish the relative dominance of local and global forms prior to the stimuli having self associations (in Experiment 3 and 4). Participants were presented with figures that comprised global squares or circles made up of local squares or circles, creating conditions in which the global shapes and their local elements were either congruent or incongruent. An effect of congruency when the task is to respond to either the global or local shape typically indicates the extent to which the non-target level of shape competes for a response with the target level (Mevorach et al. 2006; Navon 1977). Participants performed blocks of trials responding either to the global or to the local shapes. The target (global vs. local) and the congruence of the two levels of shape were varied. Next (Experiment 2) we manipulated perceptual salience to delineate how this affected performance. After this (Experiment 3) we had observers make social associations by initially conditioning the neutral shapes to labels for the self, a best friend and a stranger, giving observers just a short run of training trials[1]. We asked whether self-conditioned stimuli affect performance in a manner that is qualitatively similar way to effects with stimuli high in perceptual saliency (as in Experiment 2). In Experiment 4 we used functional magnetic resonance imaging (fMRI) to evaluate common effects of self- and perceptual saliency at a neural level.

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[1]Initially a mean of 13.17 trials per association.

If the acquired social salience of stimuli impacts visual selection in a similar manner to perceptual salience (Mevorach et al. 2006, 2009, 2010), we should find that visual selection is influenced by the social salience of the stimuli, over and above effects of the level of the target (local or global). In addition, the selection of a low salient target in the presence of a high salient distractor should be associated with activity in the left IPS (Mevorach et al. 2009, 2010). The results verified this hypothesis. Both the social and the perceptual salience of stimuli affected visual selection in a qualitatively similar manner; moreover the rejection of a socially salient distractor was modulated through the same region of the IPS as the rejection of a perceptually salient distractor (using a region of interest (ROI) analysis based on Mevorach et al. 2010, and then replicated by a whole-brain analysis). The results suggest that conditioning sensory stimuli to the self produced rapid functional and neural changes equivalent to altering the perceptual salience of stimuli. Our study provides a new way to understand how personal significance affects perception.

**Experiment 1-3: Behavioral studies**

*Materials and Methods: Experiments 1-3*

*Participants*. In Experiment 1 twenty-one college students participated (4 males, aged between 19 to 29 years, $M = 23.52 \pm 2.23$). There were twenty-four college students (4 males, aged between 19 to 28 years, $M = 23.29 \pm 2.48$) in Experiment 2 and also in Experiment 3 (4 males, aged between 19 to 28years, $M = 22.54 \pm 2.30$). All participants were right handed and had normal or corrected-to-normal vision. Informed consent was obtained prior to the experiment according to procedures approved by a local ethic committee.

*Stimuli and procedures*. Different from prior work on perceptual salience where the stimuli were compound letters (Mevorach et al. 2006, 2009, 2010), shapes (circles, squares, hexagons) were presented in hierarchical (global-local) forms (in combinations of two shapes,

across different trial blocks) and the task was to discriminate the shape at a global or local level in Experiment 1 (see Fig. 1a). Each local shape subtended $0.67° \times 0.67°$ of visual angle in width and height respectively, and each global shape subtended $5° \times 5°$ of visual angle in width and height respectively. In Experiments 1 and 3 the shapes were white solid figures, presented on a black background at one of two possible locations at above or below a white fixation of $0.58° \times 0.58°$ along the vertical midline. The center of each global shape fell $3.7°$ away from fixation. The experiment was run on a PC using E-prime software (Version 2.0) and the stimuli were displayed on a 21-inch monitor ($1024 \times 768$ at 100 Hz).

Experiment 1 was a baseline study. The participants' viewing position was 80 cm away from monitor. Each trial started with a fixation cross in the center of the screen for 500 ms, followed by a compound, hierarchical stimulus above or below fixation for 150 ms and then the fixation cross returned during a response interval of 950 ms. Participants had to discriminate the shape at a global or local level by pressing one of two keys with the right index or middle finger. On half of the trials the global and local shapes were the same (congruent trials); on the other half the global and local shapes differed (incongruent trials). A white instruction ('global task' or 'local task') appeared at the center of the screen before each block, terminated by a key press from participants. The order of the tasks was counterbalanced within participants (ABBA or BAAB). Thus, there were two within-subjects variables – the target (global vs. local) and the congruency of the global and local shapes (congruent vs. incongruent). Each participant performed 4 blocks of 48 trials following 16 practice trials. Thus each condition consisted of 48 trials. The pairings of the shapes (circle and square, square and hexagon, hexagon and circle) were counter-balanced across participants using a balanced Latin square. In order to compare the results in Experiment 1 with those in Experiment 3, the design in Experiments 1 and 3 were identical except that the shapes in Experiment 3 had a social association. The stimuli and presentation conditions were

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identical in Experiment 1 and 3 where one shape (representing an unfamiliar other in Experiment 3) was paired with another two shapes (representing the self and a best friend in Experiment 3), in separate trial blocks to form the compound stimuli.

Experiment 2 used two types of compound stimulus: high local salience and high global salience (see Fig. 1b). Stimuli with high local salience had high contrast red and white local elements. Stimuli with high global salience had individually blurred red shapes (created using abode illustrator CS4 with Gaussian Blur, with a radius of 7 pixels) (Mevorach et al. 2006, 2009, 2010). For congruent trials, when target and distractor levels vary in saliency, it is impossible to judge whether participants are responding to the appropriate level of the stimulus when the target has low saliency and the distractor high saliency (see Supp. Table 1). In contrast there is no ambiguity for incongruent trials, when the target has a different identity to the distractor(s). The analyses for Experiment 2 were performed on incongruent trials only. There were two within-subjects variables – target/distractor saliency (distractor salient vs. target salient) and the target (global vs. local). Each participant performed 8 blocks of 48 trials following 32 practice trials (48 trials per condition), with shape pairings counter-balanced across participants.

In Experiment 3, there were two phases. The responses to local-global forms were preceded by a simple shape-label conditioning task. In the conditioning task, participants named geometric shapes (square, hexagon, and circle) as the self, a named best friend or an unfamiliar other (counter-balancing the shapes across participants; see Sui et al. 2012). After this, participants judged which of three labels matched a given shape. One shape and three labels ('You', 'Friend', and 'Stranger') were presented respectively above and below a central fixation cross. Participants had to press one of three keys according to which label matched the shape. The distance between the central fixation cross and the centre of the shape/the central of the three labels was 3°. A shape subtended 3.14° × 3.14° of visual angle

and the width and height of the three labels was respectively 9.0° × 1.0°. Each trial started with the presentation of a central white fixation cross for 2000 ms and then the shape-label display for 1000 ms during which participants had to make a response. Feedback was given. The task was terminated after six consecutive correct judgments were made. After a block of learning trials, participants completed the global-local task. In this task there were blocks of trials in which the self-associated shape was paired with the shape associated to an unfamiliar other (self vs. other discrimination) and blocks in which the friend-associated shape was paired with the shape associated to an unfamiliar other (friend vs. other discrimination). The task was to discriminate the shape-associated person (e.g., self vs. unfamiliar other, friend vs. unfamiliar other) at a given level of shape (global or local) (Fig. 1c). The order of the blocks (with self vs. other and friend vs. other discriminations, with the target at the local or global level) was counterbalanced within participants. Each participant performed 12 blocks (3 sets of 4 blocks – self vs. other, friend vs. other x local or global target) of 64 trials following 32 practice trials (48 trials per condition). To reinforce the social coding of the stimuli throughout the subsequent trials with hierarchical shapes, the learning task was conducted three times, once before each set of 4 global-local blocks. The analysis on associative learning showed that participants were able to rapidly assign personal significance to neutral shapes, in line with prior studies (Sui et al. 2012, 2013) (see Supplementary Materials and Supp. Fig. 1). For the global/local task, only the data for incongruent trials were analysed. With congruent trials any difference between the self/friend and the unfamiliar other conditions could reflect facilitated responding to the target level or disruption from the distractor level (as when perceptual salience was manipulated in Experiment 2) (see Supp. Table 2). The effects of the target and distractor levels could more clearly be separated on incongruent trials (when targets and distractors differed). There were three within-subjects

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variables – the task (self vs. unfamiliar other or friend vs. unfamiliar other), the saliency (distractor salient vs. target salient), and the target level (global vs. local).

To verify the effect of learned social salience on selection, we also conducted two associative control experiments. One control experiment was identical to Experiment 3 except that we had participants judge the shape rather than the person tagged to the shape in the global/local task. In this case, implicit effects of the personal association were examined as the task did not require explicit responses to the associated information. The implicit experiment replicated the results in Experiment 3. To ensure that the result on social salience was not simply due to responses to the self-associated shape being faster than to shapes associated to other people, we conducted a further control experiment where, after personal associations were formed, participants carried out a person identification task where the association to a single shape (presented in the center of the screen so that selection of the target in a hierarchical shape was not stressed) had to be discriminated. In this case the response was the same as in the hierarchical shape task (identify whether the self or other-associated shape was present at a given level in Experiment 3) but target selection was not required. There was no effect of self vs. other discrimination with single shapes. This result rules out effects on response assignment while confirming effects of stimulus selection (when targets are selected from hierarchical figures) (see the Supplementary Materials).

## Results and Discussion

### Experiment 1: Baseline with neutral stimuli

There was no evidence of a speed-accuracy trade-off. To simplify the presentation RT and accuracy measures were combined in a single measure of response efficiency (RT/proportion correct, Townsend and Ashby 1983). A repeated measures ANOVA revealed significant main effects of target level, $F(1, 20)=40.30$, $p<0.001$, $\eta^2=0.67$, and congruency,

$F(1, 20)=10.09$, $p=0.005$, $\eta^2=0.34$. There was no interaction, $p=0.47$ (Fig. 2a). These results demonstrate both an overall global advantage (target level effect) and a congruency effect (worse performance with incongruent relative to congruent stimuli; Fink et al. 1997; Hubner 2000; Lux et al. 2004; Navon 1977; Yovel et al. 2001). There was no asymmetry in the congruency effect for local and global targets, indicating no differential access to stimulus information at the global and local shapes.

*Experiment 2: Perceptual saliency*

A repeated measures ANOVA on the efficiency data on incongruent trials showed significant main effects of target-distractor saliency[2], $F(1, 23)=93.90$, $p<0.0001$, $\eta^2=0.80$, indicating worse performance with high saliency distractors and low saliency targets, compared with when targets had high saliency and distractors low saliency. There was also a significant effect of target, $F(1, 23)=64.03$, $p<0.001$, $\eta^2=0.74$, reflecting faster responses to global than to local targets. The interaction between target-distractor saliency and target level was also significant, $F(1, 23)=8.09$, $p<0.01$, $\eta^2=0.26$. Efficiency was reduced for both local and global targets when the distractor had high salience and the target low salience (compared with vice versa), $t(23)=-8.09$ and $-4.70$, $ps<0.001$ for local and global targets respectively (see Fig. 2b). The interaction arose because this saliency effect was stronger for local targets. The results were consistent with prior research (Mevorach et al. 2006, 2009, 2010) where responses to hierarchical letters (rather than shapes, as used here) were affected by perceptual saliency at both the local and global levels.

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[2] The analyses for Experiment 2-4 were performed on incongruent trials only. When target and distractor levels vary in saliency, it is impossible to judge whether participants are responding to the appropriate level of the stimulus when the target has low saliency and the distractor high saliency. In contrast there is no ambiguity for incongruent trials, when the target has a different identity to the distractor(s).

*Experiment 3: Self-saliency*

We examined the interference effect on selection based on the social saliency of targets and distractors in the global/local task. A repeated measures ANOVA on performance efficiency for incongruent trials was conducted with the factors being task (self/other vs. friend/other stimuli), social saliency (distractor salient vs. target salient), and level of target (global or local target). There was a significant two-way interaction between the task and salience, $F(1, 23)=5.53$, $p<0.03$, $\eta^2=0.19$ (Fig. 2c). For the self vs. unfamiliar other task there was a significant main effect of social saliency, $F(1, 23)=8.05$, $p<0.01$, $\eta^2=0.26$, indicating slowed responses when distractors had high saliency (i.e., distractors were conditioned to the self) and the target low saliency (conditioned to the unfamiliar other) compared with when distractors had low saliency (unfamiliar other) and the target high saliency (the self). There was no significant interaction between social salience and target level, $p=0.46$, indicating that the interference effect occurred for both global and local targets. There was also a significant main effect of the target level, $F(1, 23)=22.17$, $p<0.001$, $\eta^2=0.49$; there were faster responses to global than to local targets. For the friend vs. unfamiliar other task there was only a significant main effect of level of target, $F(1, 23)=69.09$, $p<0.001$, $\eta^2=0.75$. There was an overall benefit for global targets (as in Experiment 1) (Fig. 2c). Performance did not vary as a function of whether the shape conditioned to the friend was a distractor or target ($p$s>0.26). The data indicate that the presence of the self shape uniquely affected selection across both local and global levels of the stimuli.

In sum, the behavioral data demonstrated interference from high saliency (self-associated) distractors on low saliency (unfamiliar other associated) targets, mimicking with the effects of perceptual saliency (in Experiment 2). Experiment 4 tested whether perceptual and self saliency operated through common neural structures (Mevorach et al. 2009, 2010).

## Experiment 4: Neural effects of self saliency

*Materials and Methods*

There were 12 right-handed participants (6 males, aged between 20 to 27 years, $M = 22.75 \pm 1.82$). The Method for Experiment 4 was identical to that in Experiment 3 except in the following aspects. Participants were first asked to associate one shape with themselves and another with their best friend. They then saw the self shape paired with a neutral shape for the global-local task. Each local element subtended $1.16° \times 1.16°$ of visual angle in width and height respectively, and each global shape subtended $6.7° \times 6.7°$ of visual angle. The compound shape appeared on a black background at one of two possible locations above or below a white fixation cross of $0.5° \times 0.5°$, centred on the vertical midline. The task was to identify the shape on the target level rather than the person associated with the shape. Participants performed shape-label conditioning before each of 3 fMRI runs. Each run consisted of 2 self blocks (global and local task) there were 96 experimental trials and 48 null trials in total. The order of the blocks was counterbalanced across runs.

*fMRI Data Acquisition*. We used a Siemens 3.0-T Trio MRI scanner to acquire T2-weighted echo planar images (EPI) blood oxygenated level dependent (BOLD) contrast. 39 oblique slices were acquired with 2 mm thickness and 1 mm gap, with a plane resolution of $2.5 \times 2.5$. We used, 90º degree flip angle, 33 ms echo time and 2300 ms slice repetition time. Images were acquired using an eight channel phase array coil with a sense factor of 2. The slices covered most of the brain including the entire temporal cortex.

*Data analysis*. The data were analyzed using SPM8 (Wellcome Department of Imaging Neuroscience, London; www.fil.ion.ucl.ac.uk/spm). EPI volumes were spatially realigned to correct for movement artifacts, transformed to Montreal Neurological Institute (MNI) standard space (Ashburner and Friston 2005), and smoothed using 8 mm Gaussian kernel to account for residual inter-subject differences.

*Statistical analysis.* A voxel-based analysis was performed in two steps. First, for each individual, we estimated the effect size on each condition averaged across the three sessions. We modelled the onset of each trial in each of experiment conditions (distractor/target salience × target level). To correct for signal changes due to head movement, the 6 realignment parameters were also included. An additional set of harmonic regressors were used to account for any low-pass frequency variance within the data across time with a cut-off of 1/128 Hz, as well as the specific session effects. For each participant, we computed the averaged estimated response across the three sessions in each experimental condition. We focused on 4 experimental conditions on incongruent trials: distractor salient (self as distractor) in the global target condition, target salient (self as target) in the global target condition, distractor salient (self as distractor) in the local target condition, and target salient (self as target) in the local target condition.

*ROI and whole-brain analysis*. In order to test the hypothesis that the social salience of a stimulus impacts on visual selection in a similar manner to the effects of perceptual salience, we conducted an ROI analysis by extracting peak beta values for each experimental condition from the left IPS region [-30 -68 34] implicated in rejecting salient distractors in prior work on perceptual salience (Mevorach et al. 2009). We also carried out a whole-brain analysis to verify the ROI result. For the whole-brain analysis, we report those results showing a significant effect at $p<0.005$ uncorrected across the whole brain and an extent threshold of >100 voxels.

## Results and Discussion

Analysis of behavioural efficiency on incongruent trials revealed a reliable main effect of social salience (distractor salient vs. target salient), $F(1, 11)=7.03$, $p<0.03$, $\eta^2=0.39$. Performance was worse when the distractor had high social salience (the self) and the target

low social salience (neutral), compared with when the distractor had low social salience (neutral) and the target high social salience (self). This is consistent with the data in Experiment 3. There was no significant main effect of the target level and no interaction between target and social salience, $p$=0.35 and 0.18 (Fig. 3a)

Similar to prior studies on perceptual salience (Mevorach et al. 2009, 2010), we contrasted brain activation for incongruent trials for the self shape as a distractor to the self shape as a target. The ROI analysis, focusing on the left IPS [-30 -68 34] (see Mevorach et al. 2009) also revealed a significant main effect of social saliency, $F$(1, 11)=10.42, $p$<0.01, $\eta^2$=0.49; there was increased activation when the self was the distractor relative to when the self was the target (and the neutral shape was the distractor) (Fig. 3b). Neither the effect of the target level nor the interaction between target and social saliency were significant, $p$=0.76 and 0.52. This result was confirmed by the whole-brain analysis. There was increased activation in the left posterior parietal cortex (centred around the IPS; see Fig. 4) when participants had to ignore the self (i.e. the self as distractor vs. the self as target). There was increased activity in the left IPS when the self was a distractor relative to when it was a target, for both local and global targets (Fig. 4). The results replicated the findings from studies of perceptual salience and show a similar activity pattern in common regions (Mevorach et al. 2009, 2010).

The data showed that when participants had to ignore the self (i.e. the self as distractor vs. the self as target), there was increased activation in the left posterior parietal cortex replicating results previously found when perceptually salient distractors must be ignored.

**General Discussion**

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Experiments 1 and 2 here are baseline studies showing (i) local-global responses to neutral shapes (Experiment 1), and (ii) effects of perceptual saliency when local and global levels are altered to selectively enhance their saliency (Experiment 2; see also Mevorach et al. 2006, 2009, 2010). Strikingly, these behavioral effects of perceptual saliency were replicated on neutral shapes briefly conditioned to be associated with the self relative to other people. Having the self-conditioned shape as a distractor rather than a target selectively disrupted performance while no such effect was found for shapes conditioned to a friend. This occurred for both global and local targets. Thus having the self-conditioned shape at the global level was equivalent to blurring the shapes, and having the self-conditioned shape at the local level was equivalent to making the local elements high contrast and different from each other. These effects arose after just a few (<15) learning trials, demonstrating that a new self-association rapidly transformed perceptual salience. While perceptual learning leads to exposure-based transformation of visual perception (Dosher and Lu 1998; Karni and Sagi 1993; Li et al. 2009; Seitz and Watanabe 2003; Watanabe et al. 2001), self-conditioning to sensory stimuli generates a fast modulation effect equivalent to enhancing the perceptual salience of the conditioned stimulus.

We also measured brain activity to self-conditioned stimuli (Experiment 4) and showed increased activation when socially salient distractors had to be rejected (self as distractor) in the same region as that found when participants must reject perceptually salient distractors (taking an ROI from Mevorach et al. 2009). The results indicate that rapidly-formed self-associations change the neural response in a manner that is qualitatively similar to effects produced by changing the perceptual saliency of stimuli. In particular, there was enhanced activation of left IPS when the task required participants to select the neutral shape and to ignore the self-associated shape. Previous studies have found activation of the left IPS when perceptually salient distractors have to be ignored and this has been causally linked

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with down-regulation of early visual regions responding to the salient distractors (Mevorach et al. 2010). For example, suppressive TMS applied to the left IPS leads to increased activity in early visual regions, consistent with the removal of top-down suppression from the IPS. Here we suggest that self-associated distractors engaged similar suppressive control processes when they had to be ignored. An alternative function of left IPS is associated with top-down control of spatial attention (Bouvier 2009; Bressler et al. 2008; Corbetta et al. 2000; Posner et al. 1984), but the effect typically occurs bilaterally, in both hemispheres. Some studies have also reported that the left parietal cortex is associated with local processing while right parietal cortex is related to global processing (e.g., Fink et al. 1997; Weissman and Woldorff 2005). These studies typically had participants to discriminate a target occurring at either the global or local level of a stimulus. In contrast, we had participants make a judgment to either global or local targets, and they did not need to shift spatial attention between global and local levels in a block. As shifts in spatial attention were not required, and since our effects occurred irrespective of the level of the target (global or local), our effects were unlikely to be due to shifts in spatial attention or specialisation of local vs. global processes in the left IPS (e.g., Mevorach et al. 2009, 2010). The left IPS is also thought to be associated with motor control; in particular the anterior part of left IPS is linked to hand movements and the posterior portion of the left IPS modulates visual feedback for movements (e.g., Thaler and Goodale 2011). In the current study, the effects are on visual selection not response control (see Supplementary materials) and again seem unrelated to this alternative account of left IPS function.

The present evidence adds to other data in studies of the self showing that self-related information has high processing priority relative to other types of social information. For example, participants are faster to respond to their own than to other peoples' faces, both when the task requires explicit face recognition (categorizing faces as either the self or a

familiar other) (Sui and Humphreys 2013), and when judgements about face orientation are required without explicit face recognition (Keenan et al. 1999; Keyes and Brady 2010; Sui and Han 2007). Attention can also be automatically attracted by self-related information presented as a distractor compared to when distractors are associated with other people (Brédart et al. 2006; Gronau et al. 2003; Sui et al. 2012). However, these studies have used highly familiar self-related stimuli learned over long periods of time, and they do not touch on whether new self-associations can quickly modulate perceptual processing. It is also difficult in such studies to rule out effects due to the perceptual properties of the particular stimuli. Here we used neutral shapes and showed how self-conditioning changed their initial behavioral response (in the baseline study Experiment 1) to generate asymmetric interference from self-associated distractors (Experiment 3). Recent work has consistently shown the effect of personal association on perceptual matching in various contexts and with different task demands (Sui et al. 2012). In particular, personal associations engaged a core part of the self-representation network (vmPFC) and the social attentional network (LpSTS), and the strength of coupling between these two neural regions predicts the strength of personal association effects (Sui et al. 2013). The present study differs from these prior studies in focusing on whether the social salience of a stimulus affects visual selection in a similar manner to the effects of perceptual salience, and whether the neural response when socially salient distractors have to be ignored matches that found when perceptually salient distractors are ignored (Mevorach et al. 2009, 2010). This change in focus generated substantial differences between the current study and our prior work (Sui et al. 2012, 2013). First, in prior work, participants always responded to the particular coupling of the associated shape and a label whereas here they respond directly to the associated identity of a shape, which was embedded within or formed a hierarchical figure (and required selection of the target shape from a distractor at the other level). Second, within the hierarchical shape, the self or

familiar-other associated shape was always present along with a neutral (non response-related) shape. Hence we no longer see activation uniquely associated with the presence of the associated shape (e.g., in vmPFC and LpSTS), as it was also present in the contrast between the critical displays. As predicted we do see changes in brain regions involved in selecting the target shape as a function of whether the self-associated shape is a distractor.

Following the current study, interesting questions remain about whether perceptual and social saliency interact in selection (i.e. when the two types of saliency co-vary). Prior work has showed that perceptual salience operates in a bottom-up fashion, and responses to low saliency target in the presence of high salient distractors leads to down-regulation of distractor-driven activity in occipital visual cortex (Mevorach et al. 2010). In contrast social salience may reflect top-down control processes when a set for the social association is formed. Whether this social association also modulates processing in early visual cortex is unknown. Some researchers have also argued that self-saliency may result from differential effects of reward (Behrens et al. 2008; Northoff and Hayes 2011) or positive emotion (Ma and Han 2010). For example, Sui et al. (2012) compared the effects of self-conditioning with the effects of conditioning shapes to have different reward values. Perceptual matching was faster and more accurate for both self-conditioned shapes and shapes conditioned to high reward, and both forms of conditioning led to reduced effects of stimulus contrast reduction on perceptual discrimination. These results suggest that self-saliency may reflect increased reward values linked to the self compared with other people. It is interesting too that the association of high reward values to a stimulus have also been argued to change the perceptual saliency of the stimulus (e.g., Hickey and van Zoest 2012). Reward may be a common underlying mechanism linking social to perceptual salience. This speculation should be tested in future research.

Overall, though, our evidence suggests that the rapid self-conditioning of stimuli can provide a new means of examining social modulation of perception without confounds from stimulus familiarity and complexity. Going beyond this, here we show that, once formed, personal associations can modulate the saliency of stimuli and subsequently impact on visual selection. We suggest that self-conditioning can dynamically tune attention in the environment by altering the social saliency of stimuli.

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**Figure 1** Examples of stimuli and procedures in Experiment 1 (a), Experiment 2 (b), and Experiment 3 (c). Three types of shapes (square, circle, and hexagon) in each experiment were counterbalanced across participants, and formed hierarchical shapes for the congruent and incongruent trials, and global-salience and local-salient trials. The targets appeared equally above or below fixation.
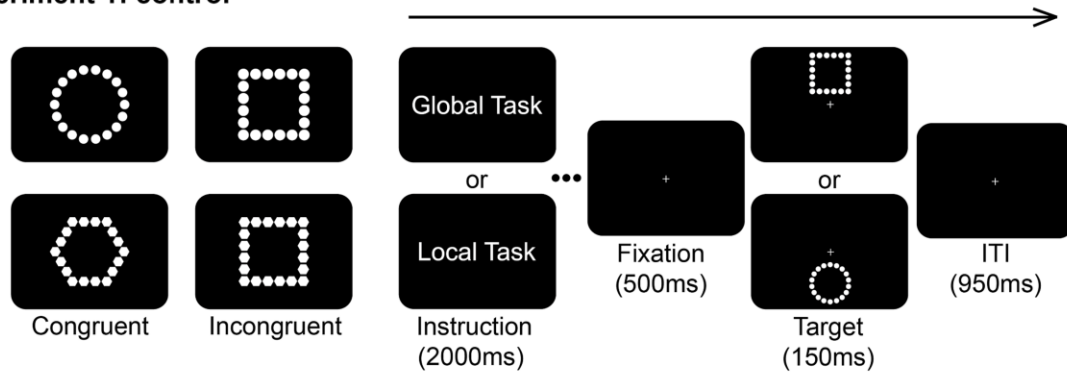
**Figure 2** (a) The efficiency of responding as a function of the target (global vs. local) and item congruency (congruent vs. incongruent) in Experiment 1. (b) Experiment 2 manipulated the perceptual salience of stimuli. The data show the efficiency for incongruent trials as a function of the level of target (global vs. local), and the salience level (distractor-salient vs. target-salient). (c) Experiment 3 manipulated the social salience of stimuli. The data demonstrated the efficiency of performance on incongruent trials as a function of the target (global vs. local), the task (self vs. unfamiliar other or friend vs. unfamiliar other), and the level of social salience (distractor-salient vs. target-salient). Error bars represent standard errors.

**Figure 3** (a) Behavioral efficiency measures for incongruent trials as a function of the level of the target (global vs. local) and the level of social salience (distractor salient vs. target salient) in Experiment 4. (b) Region of interest analysis on a region [-30 -68 34] from previous study of perceptual salience (Mevorach et al. 2009). The peak estimate effect size on neural responses as a function of the level of salience (distractor-salient vs. target-salient) and the level of the target (global vs. local). Neural responses were greater for the self shape as distractor than the self shape as target. Error bars represent standard errors.
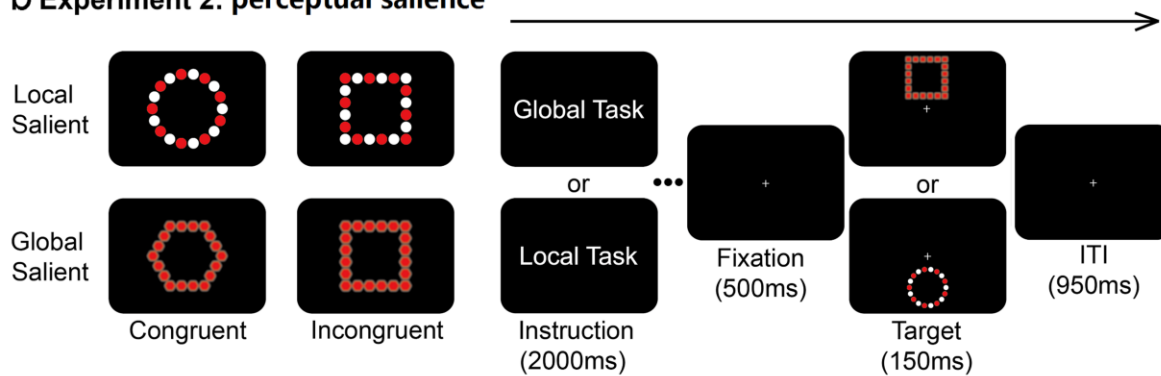
**Figure 4** Data show the results of the whole-brain analysis. (a) The peak estimated beta values for the effect of self salience were extracted from a region at [-20, -66, 56] as a function of the level of salience (distractor-salient vs. target-salient) and the level of the target

(global vs. local). Similar to the ROI result, neural responses were greater for the self shape

as distractor than the self shape as target. Error bars represent standard errors. (b) The

contrast result between self as distractor and self as target in the brain.

## a Experiment 1: control

Congruent  Incongruent

Global Task  or  ••• Local Task
Instruction (2000ms)

Fixation (500ms)

or

Target (150ms)

ITI (950ms)

## b Experiment 2: perceptual salience

Local Salient

Global Salient

Congruent  Incongruent

Global Task  or  ••• Local Task
Instruction (2000ms)

Fixation (500ms)

or

Target (150ms)

ITI (950ms)

## c Experiment 3: social salience

⬡ Self  ☐ Friend  ⚪ Unfamiliar

Local Salient

Global Salient

Self Block  Friend Block
Incongruent

Global Task  or  ••• Local Task
Instruction (2000ms)

Fixation (500ms)
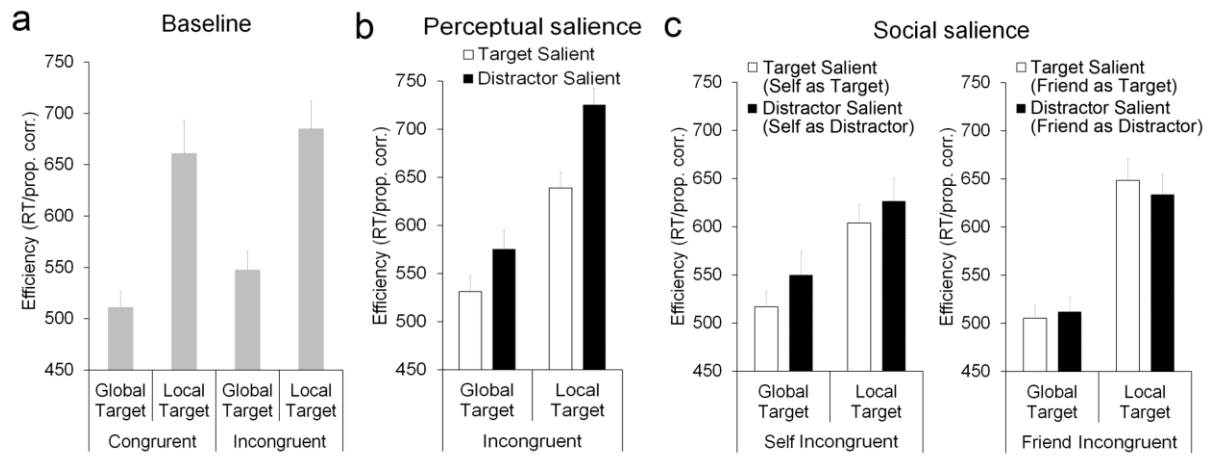
or

Target (150ms)

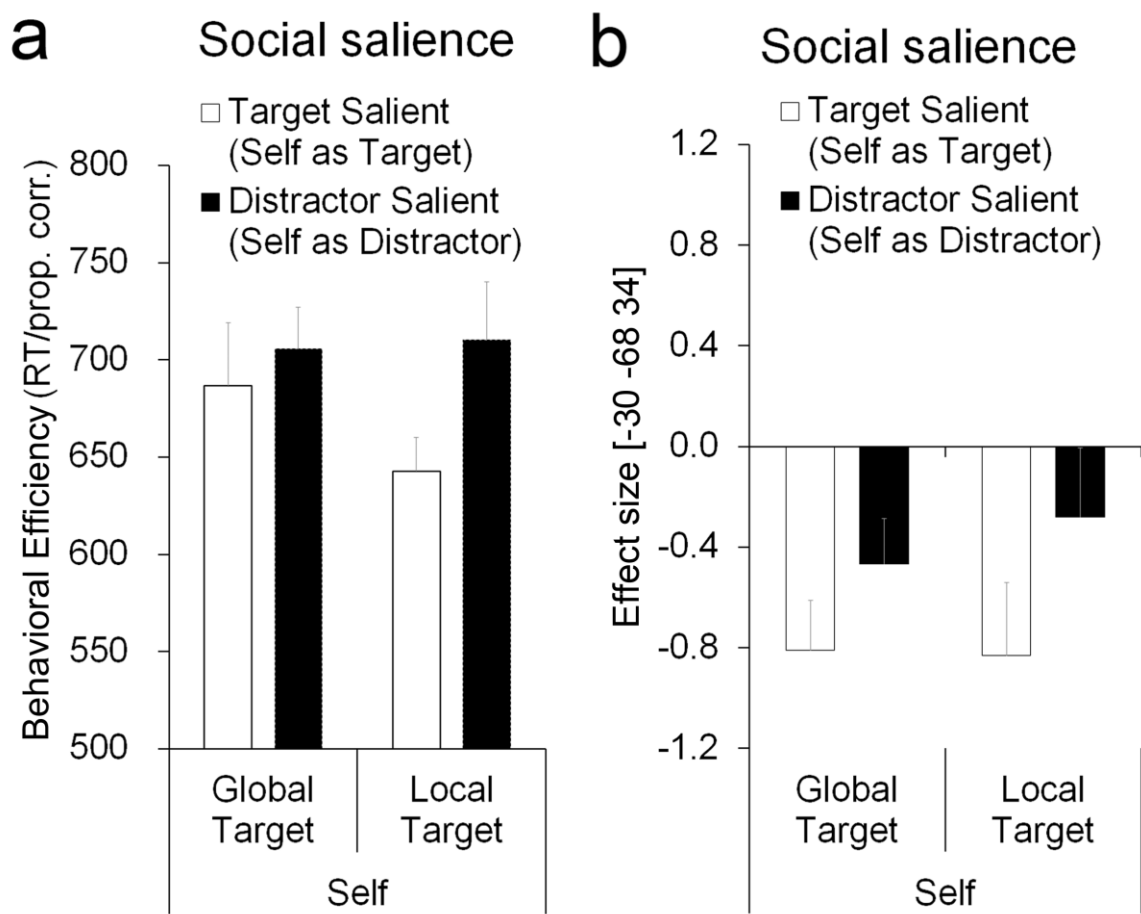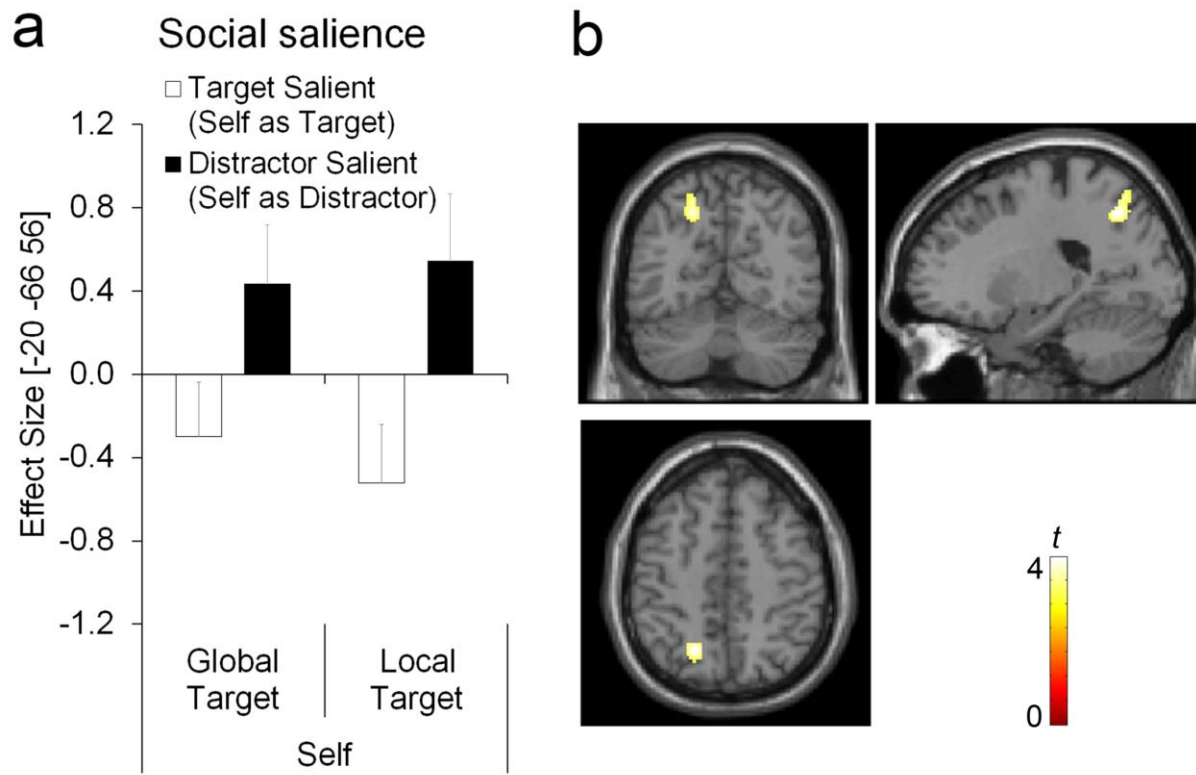ITI (950ms)
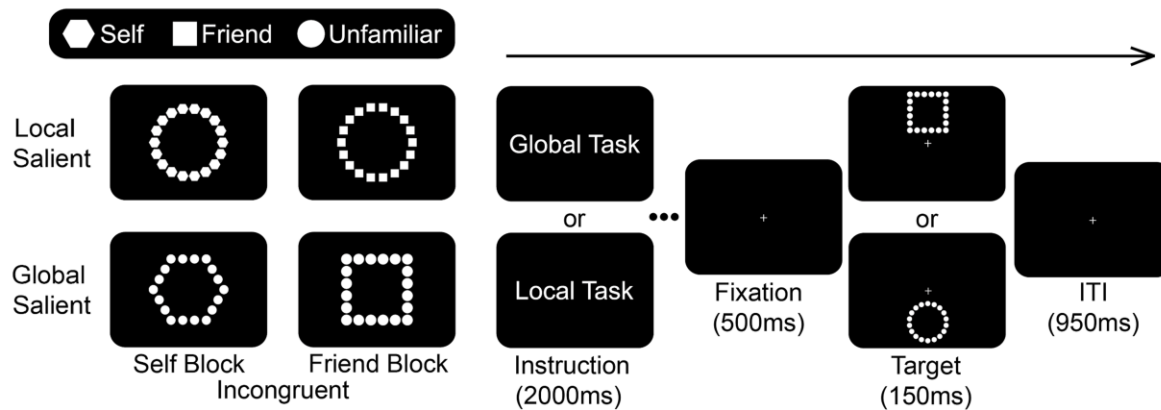
Figure 1

Figure 2

Figure 3

Figure 4

**Supplementary information**

**The effect of associative learning in Experiment 3**

Experiment 3 had two stages. First participants learned a shape-label association, and then completed a global/local task. For the performance of shape-label association, the number of trials to learn the shape-label association was assessed using a repeated measures ANOVA with two within-subjects variables – association type (self, friend, or unfamiliar other) and association block (1, 2, or 3). There was a significant main effect of association block, $F(2, 46)=6.03$, $p=0.005$, $\eta^2=0.21$ (Supp. Fig 1); the trials to reach criterion decreased across the blocks. There was also a significant effect of association type, $F(2, 46)=3.60$, $p<0.05$, $\eta^2=0.14$, however pairwise comparisons failed to show differences between any two associations ($p$s>0.13). There was no interaction between association type and association block, $p=0.15$. The mean trials to learn were 13.17, 9.54 and 8.01 trials for blocks 1, 2 and 3 respectively.

**Control Experiments for Experiment 3**

*Materials and Methods*

*Participants.* There were twenty-three participants (4 males, aged between 19 to 28 years, M = 21.09±1.91) in an implicit social salience experiment, and also in the response control experiment (4 males, aged between 19 to 28 years, M = 24.00± 2.20).

*Stimuli and procedures.* In an implicit social salience experiment, following the association task, participants had to make a simple shape recognition decision (e.g. is the local or global shape a circle or square?) rather than identifying the person associated with a shape in Experiment 3 (e.g. self or unfamiliar other). In addition, the stimuli were one of two sizes. Each local shape subtended either 1.21° or 1.38° × 1.21° or1.38° of visual angle in width and height respectively, and each global shape subtended either 7° or 8° × 7° or 8° of

visual angle in width and height. Other aspects were identical to Experiment 3. The data

analysis on associative learning showed that participants were able to rapidly tag personal

significance with neutral shapes in line with prior studies (Sui et al. 2012) (see

Supplementary Materials and Supp. Fig. 2). For the global-local task, only the data for

incongruent trials were analyzed. Data for congruent trials are reported in Supp. Table 3.

We also conducted associative control experiment where single shapes were presented.

After forming the same social associations to shapes, we had participants identify single

shapes (as self, friend or unfamiliar other) presented at fixation (with separate blocks for self

vs. other and friend vs. other discriminations). First, participants learned a shape-label

association which was identical to Experiment 3. After associative learning, they then

performed a discrimination task to a single shape-associated shape, $3.14° \times 3.14°$ in height

and width presented in the centre of the screen. Similar to Experiment 3, separate blocks of

trials required discriminations between self and other-associated shapes or between friend

and other-associated shapes. Each trial started with a 500 ms fixation cross in the centre of

the screen, which was subsequently replaced by the single shape stimulus for 150 ms. After

this, the fixation cross returned throughout a response interval of 950 ms. Participants were

instructed to discriminate whether the shape was linked to the self/friend or an unfamiliar

person by pressing one of two keys with the right index or middle finger. There were 48

experimental trials per condition following 12 practice trials.

### *Results*

The results observed in Experiment 3 were replicated in the implicit social salience

experiment. There was a significant three-way interaction of the task (self/friend vs.

unfamiliar other), level of social salience (distractor salient vs. target salient), and level of

target (global vs. local), $F(1, 22)=4.86$, $p<0.04$, $\eta^2=0.18$ (Supp. Fig. 3). The interaction effect

resulted from the self vs. other task, where there was a significant main effect of social

salience, $F(1, 22)=4.96$, $p<0.04$, $\eta^2=0.18$. In contrast, the analysis for the friend vs. other task did not show any significant effects, $p$s$>0.28$.

To ensure that this result on social salience was not simply due to responses to the self-associated shape being faster than to shapes associated to other people, we conducted a further control study with single shapes (rather than hierarchical letters). For associative learning, the analysis did not show a significant effect of association type (self, friend, or unfamiliar other), $p=0.52$. There were also no effects of social salience on shape recognition (self/friend vs. unfamiliar other), $p=0.12$; no effect of the task (self vs. friend), $p=0.78$, and no interaction, $p=0.77$. Thus, there was a differential effect of self-association only when shapes had to be selected in hierarchical forms, and not at a response level.

**Supplementary table 1.** Mean and standard deviation of efficiency measures for congruent trials as a function of target/distractor saliency (distractor salient vs. target salient) and the level of the target (global vs. local) in Experiment 2.

|  | Target/distractor saliency | |
| --- | --- | --- |
|  | Distractor salient | Target salient |
| Global target | 504 (54) | 515 (53) |
| Local target | 707 (132) | 527 (71) |

**Supplementary table 2.** Mean and standard deviation of efficiency measures for the congruent trials as a function of the task (self vs. unfamiliar other, or friend vs. unfamiliar other), the level of social salience (self vs. unfamiliar other, or friend vs. unfamiliar other), and the level of the target (global vs. local) in Experiment 3.

| | Self/Other task | | Friend/Other task | |
|---|---|---|---|---|
| | Self | Other | Friend | Other |
| Global target | 493 (60) | 517 (129) | 489 (63) | 496 (69) |
| Local target | 591 (110) | 592 (101) | 601 (125) | 589 (129) |

**Supplementary table 3.** Mean and standard deviation of efficiency measures for congruent trials as a function of the task (self vs. unfamiliar other, or friend vs. unfamiliar other), the level of social salience (self/friend vs. other target), and the level of the target (global vs. local) in implicit social salience experiment for Experiment 3.

| | Self/Other task | | Friend/Other task | |
|---|---|---|---|---|
| | Self | Stranger | Friend | Stranger |
| Global target | 526 (71) | 507 (59) | 529 (79) | 514 (80) |
| Local target | 562 (86) | 546 (88) | 547 (85) | 546 (90) |

# Supplementary figure legends

**Supplementary figure 1.** Data for the associative learning trials in Experiment 3: the number of trials to reach learning criterion as a function of the type of association (self, friend, or unfamiliar other) and the training block (1, 2, or 3). Error bars represent standard errors.

**Supplementary figure 2.** Data for the associative learning trials in an implicit social salience experiment for Experiment 3: the number of trials to reach learning criterion as a function of the type of association (self, friend, or unfamiliar other) and the training block (1, 2, or 3). Error bars represent standard errors.

**Supplementary figure 3.** Data in implicit social salience experiment for Experiment 3 demonstrated the efficiency of performance on incongruent trials as a function of the target (global vs. local), the task (self/other vs. friend/other), and the level of social salience (global-salient vs. local-salient). Error bars represent standard errors.
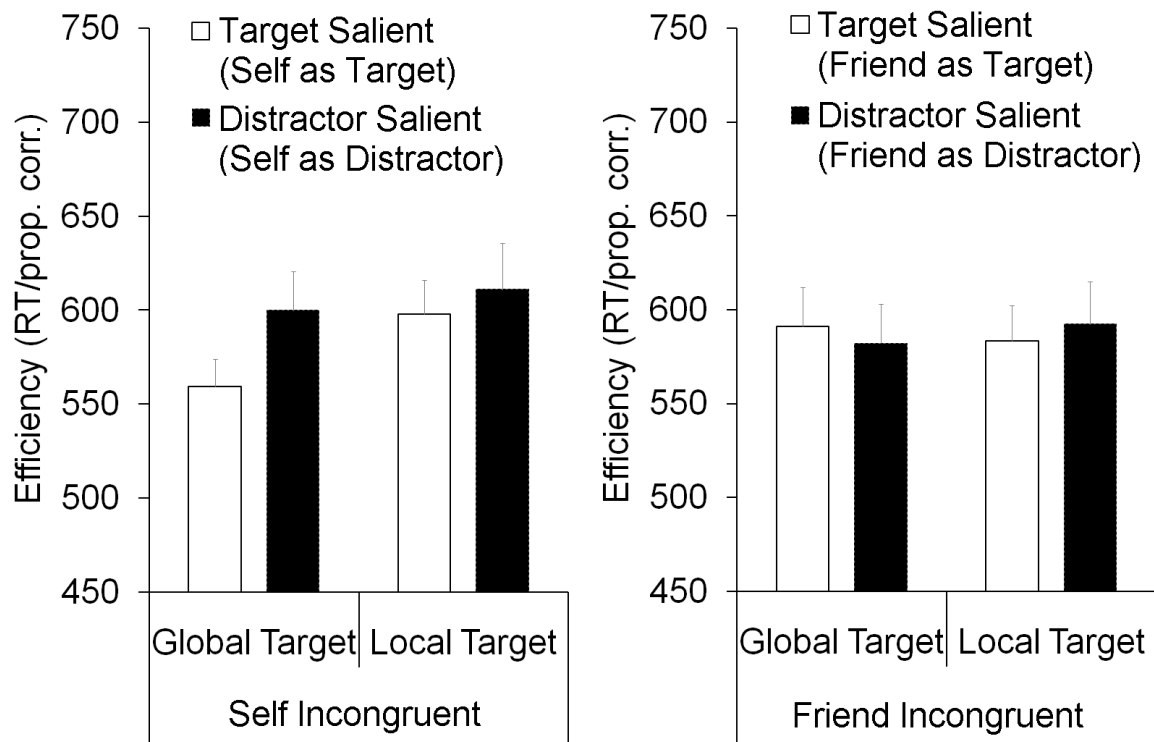
Supp. Fig. 1

## Associative learning

□ Self ■ Friend ■ Other

*Number of learning trials* (y-axis)

*Associative learning block* (x-axis): 1, 2, 3
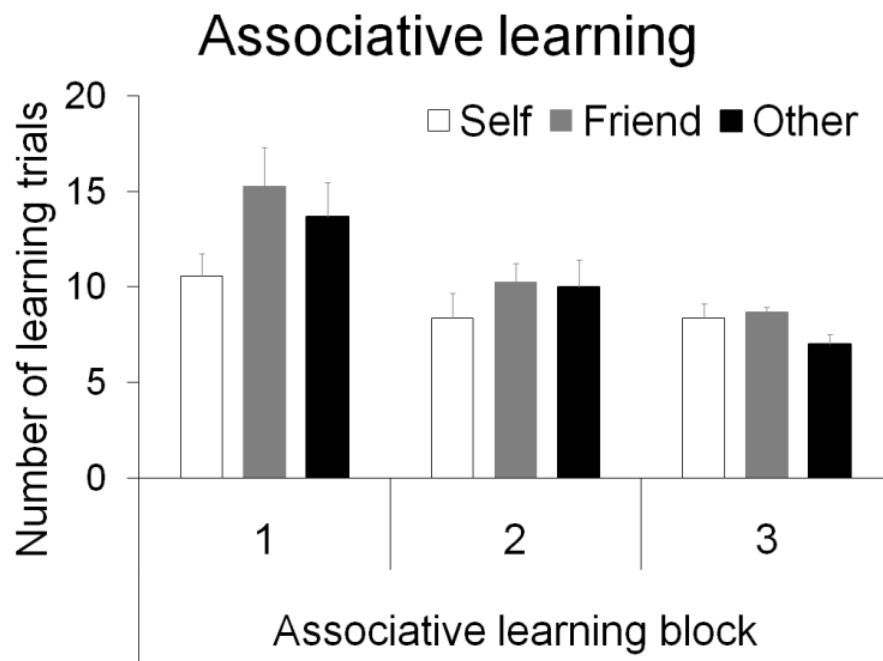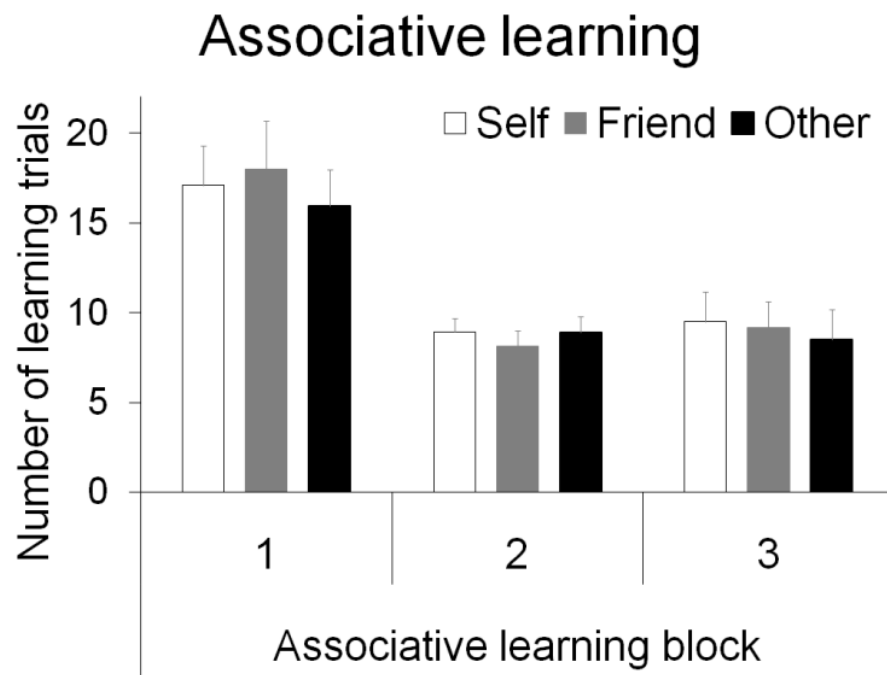
Supp. Fig. 2

## Social salience

Supp. Fig. 3