Acta Psychologica 180 (2017) 33–39

Contents lists available at ScienceDirect

Acta Psychologica

journal homepage: www.elsevier.com/locate/actpsy

Role of hand dominance in mapping preferences for emotional-valence words to keypress responses

Xiaolei Song[a], Jing Chen[b], Robert W. Proctor[c,*]

[a] School of Psychology, Shaanxi Normal University, Xi'an, China
[b] Department of Psychology, New Mexico State University, USA
[c] Department of Psychological Sciences, Purdue University, 703 Third Street, West Lafayette, IN 47907-2081, USA

A R T I C L E I N F O

Keywords:
Affective coding
Stimulus-response compatibility
Two-choice reactions

A B S T R A C T

When a crossed-hands placement (right hand presses left key; left hand presses right key) is used in a two-choice spatial reaction task, the mapping of left stimulus to left key and right stimulus to right key yields faster responses than the opposite mapping. In contrast, de la Vega, Dudschig, De Filippis, Lachmair, and Kaup (2013) reported that when right-handed individuals classified words as having positive or negative affect, there was a benefit for mapping positive affect to the right hand (left key) and negative affect to the left hand (right key). The goal of the present study was to replicate and extend this seemingly distinct finding. Experiment 1 duplicated the design of that study without including nonword "no-go" trials but including a condition in which participants performed with an uncrossed hand placement. Results corroborated the benefit for mapping positive to the right hand and negative to the left hand with the hands crossed, and this benefit was as large as that obtained with the hands uncrossed. Experiment 2 confirmed the importance of the dominant/subordinate hand distinction with left-handed participants, and Experiment 3 showed, with right-handed participants, that it does not depend on which limb is placed over the other. The results verify that the mapping advantage for *positive* → right/*negative* → left is indeed due to the distinction between dominant and subordinate hands. Possible reasons for the difference between these results and those obtained with spatial-location stimuli are considered.

PsycINFO classification

2340
2360
2346

1. Introduction

When responding to a left or right stimulus with a left or right keypress, executed with the corresponding hand, people are faster when the stimulus-response mapping is left → left and right → right than when it is left → right and right → left [the spatial stimulus-response compatibility (SRC) effect; see Proctor & Vu, 2006, for a review]. A similar correspondence benefit, called the Simon effect, is obtained when left or right stimulus location is task-irrelevant and another dimension such as color is relevant (the Simon effect; Lu & Proctor, 1995; Simon, 1990).

Whether the crucial response factor is left vs. right hand or left vs. right location of the response key is an issue of theoretical importance. This issue has been investigated in several studies by using a crossed-hands placement in which the left key is pressed by the right hand and the right key by the left hand. The consistent finding has been that the SRC and Simon effects are mainly a function of key location and not hand location, implying that response selection is based on spatial response codes. This result has been obtained for visual and auditory SRC tasks (e.g., Anzola, Bertoloni, Buchtel, & Rizzolatti, 1977; Roswarski & Proctor, 2000), and visual and auditory Simon tasks (e.g., Proctor & Shao, 2010; Wallace, 1971). Moreover, when participants press left and right keys with sticks that are crossed so that the responding hand is contralateral to the switch it operates, switch location and not hand location determines compatibility (Riggio, Gawryszewski, & Umiltà, 1986). Thus, the finding that the compatibility effects in two-choice spatial tasks are controlled by response location is consistent and replicable.

Another line of research has provided evidence that people tend to associate words with positive affect to the side of space that corresponds to their dominant hand and words with negative affect to the side corresponding to their subordinate hand. For example, Casasanto (2009) found that right-handed persons tended to draw "good" animals on the right side and "bad" animals on the left side, whereas left-handed

* Corresponding author at: Department of Psychological Sciences, Purdue University, 703 Third Street, West Lafayette, IN 47907-2004, USA.
E-mail address: proctor@psych.purdue.edu (R.W. Proctor).

http://dx.doi.org/10.1016/j.actpsy.2017.08.007
Received 10 April 2016; Received in revised form 24 May 2017; Accepted 10 August 2017
Available online 17 August 2017
0001-6918/

persons showed the opposite preference. Casasanto and Chrysikou (2011) reported evidence that this association of good with dominant hand is due to motor fluency: Hemiparesis patients who were right-handed prior to the stroke that caused brain damage showed an association of good with right if they had lost use of their left hand but good with left if they had lost use of their right hand. Additionally, students who performed a motor task with a cumbersome glove on the left hand still paired good with right, whereas those who performed the task with the glove on the right hand paired good with left. Casasanto (2011) summarizes the evidence for a preferred mapping of positive affect to dominant hand and negative affect to nondominant hand, arguing more generally for a *body-specificity hypothesis*:

> To the extent that the content of the mind depends on the structure of the body, people with different kinds of bodies should tend to think differently, in predictable ways. This is the *body-specificity hypothesis* (Casasanto, 2009). When people interact with the physical environment, their bodies constrain their perceptions and actions (p. 378).

To investigate whether an association between affective valence and dominant side influences response times (RTs) in Simon-type and SRC tasks, de la Vega, de Filippis, Lachmair, Dudschig, and Kaup (2012) conducted four experiments using lists of words with positive (e.g., *friends*) and negative (e.g., *poverty*) connotations. For right-handed participants, no influence of affective category was found when affect was task-irrelevant (i.e., for word-nonword lexical decisions), but when the words were to be classified according to their affective valence, there was a 24-ms benefit for the mapping positive → right/negative → left over the opposite mapping. Left-handed participants showed an opposite 32-ms mapping preference for positive → left/negative → right. Thus, these results provide evidence of an SRC effect for which the preferred mapping associates positive with the dominant hand and negative with the subordinate hand, but no evidence for automatic activation of a particular response when affect was task-irrelevant.

As in the studies of spatial SRC and Simon effects, the preference of right-handed participants for the positive → right/negative → left mapping could be a function of the hand distinction or the right vs. left position of the response key. Therefore, de la Vega, Dudschig, De Filippis, Lachmair, and Kaup (2013) had right-handed participants perform with a crossed-hands placement in which the right hand operated the left key, and vice versa. In two experiments, which differed only in whether the instructions referred to response hands or response keys, responses were 20-ms faster when positive words were assigned to the right hand and negative words to the left hand, than with the opposite mapping, even though the hands were placed on the left and right keys, respectively. This outcome implies that coding of responses in terms of the dominant hand or its location, rather than in terms of the left or right location of the response key, is the predominant source of the SRC effect for mapping stimulus affect to left and right responses.

Although the body-specificity hypothesis predicts the pattern of SRC effects obtained by de la Vega et al. (2012) and de la Vega et al. (2013), effects of this type that are based on asymmetries of stimulus and response sets are also in agreement with a polarity correspondence principle proposed by Proctor and Cho (2006; see also Proctor & Xiong, 2015). According to this principle, in two-choice tasks, participants code the stimulus and response alternatives as + or − polarity based on relative salience, and performance is best for the mapping that maintains correspondence of the respective code polarities. Proctor and Cho focused on tasks in which left-right spatial coding of responses seems to predominate (mappings of up or down stimulus locations, numerical parity or magnitude, and implicit associations), proposing that the right response is coded as + polarity and the left response as − polarity, rather than the dominant vs. subordinate hand. But, as de la Vega et al. (2013, p. 277) noted, the polarity principle provides "an alternative explanation for the findings presented here" if the plausible assumption is made "that of the two response alternatives, dominant hand vs. non-dominant hand, the dominant hand should be the more salient response alternative." A limitation of this shift to hand dominance as the determining factor, pointed out by Huber et al. (2015) in their article examining embodied markedness of parity, is that such an account is ad hoc and should not be favored without additional evidence.

To summarize, the results obtained by de la Vega et al. (2013) with a crossed-hands placement are counter to those of many other SRC studies using that placement, which instead implicate spatial coding of response keys or goals. Additionally, the results are counter to the emphasis that Proctor and Vu (2006) placed on spatial relations for the coding of response alternatives when they applied the polarity principle to other SRC effects based on coding asymmetries. Therefore, replication of de la Vega et al.'s results in a separate study is essential: Experiment 1 was designed to provide such a replication, determining whether we could verify de la Vega et al.'s (2013) results for right-handers and whether there is any reduction in effect size with the crossed-hands placement compared to the uncrossed one.

If hand dominance is the critical factor, as the body-specificity hypothesis proposes, then left-handed participants should show the opposite pattern of right-handed participants: the mapping of positive → left-hand/negative → right-hand should yield better performance than the alternative mapping, regardless of whether the hands are crossed or uncrossed. Due to the limited availability of left-handed participants, in Experiment 2 we tested this population only with the crossed-hands placement for which they have not previously been tested. Finally, because participants in Experiments 1 and 2 responded with their dominant hand placed over the subordinate hand for the crossed-hands placement, in Experiment 3 we had right-handed participants perform with the subordinate hand left hand on top in order to ensure that vertical placement of the limbs was not the determining factor for the mapping effects.

2. Experiment 1

Experiment 1 was a replication of de la Vega et al.'s (2013) study, with a couple of changes. The initial experiment in de la Vega et al.'s (2012) earlier study used a lexical-decision task, for which a third of the stimuli were nonwords. So, de la Vega et al. (2013) continued to include nonwords as "no-go" trials in their SRC experiments. Inclusion of no-go trials essentially introduces a third response alternative that can interfere with task preparation (Lenartowicz, Yeung, & Cohen, 2011) and lengthen RT on the go trials. Because there is no reason why a preferred mapping of stimulus affect to hand should depend on inclusion of no-go trials, we did not include any.

Also, de la Vega et al.'s (2013) experiments in which responses were made with a crossed-hands placement did not include conditions with an uncrossed-hand placement (although the method seems to have been similar to that of their 2012 study in which the hands were uncrossed). Therefore, in our Experiment 1 we incorporated an uncrossed-hands placement for direct comparison to the crossed-hands placement, allowing determination of whether the right-left hand distinction is the sole factor contributing to the mapping effect. If so, the advantage for the mapping of positive to right hand and negative to left hand with the hands crossed should be similar in size to the advantage obtained with the hands uncrossed.

2.1. Method

2.1.1. Participants

Participants were 80 students enrolled in Introductory Psychology courses at Purdue University who took part for credits toward a course requirement. Handedness was assessed prior to the experiment using the Edinburgh inventory (Oldfield, 1971), for which a positive score indicates dominance of the right hand, with the maximum value being 100. Forty students (22 males, $M = +77.2$; score range: +46 to

+100), mean age of 20.6 years ($SD = 2.1$) were randomly assigned to perform with the crossed-hands placement, under which the dominant right hand was crossed up the subordinate left hand, and 40 students (18 males, $M = +72.5$; score range: +41 to +100), mean age of 20.2 years ($SD = 1.8$), to perform with the uncrossed-hands placement. All participants were native English speakers and naïve to the purpose of the study. They all reported having normal or corrected-to-normal vision and normal hearing.

2.1.2. Stimuli and apparatus

Stimulus materials were 40 English words (see Appendix), 20 with positive connotation (e.g., *nice*; number of letters: $M = 7.1$, range = 4–11) and 20 with negative connotation (e.g., *evil*; number of letters: $M = 7.0$, range = 4–11), used in a prior study by Zhang, Proctor, and Wegner (2012). Eight additional words (four positive and four negative) served as stimuli during practice trials. Because of the nature of the task, no neutral words were used.

The experiment was conducted on a personal computer, with stimulus presentation, response recording, and data collection controlled by *E*-Prime 2.0 software. The stimuli were presented on a 17-in. LCD monitor, viewed by the participant from a distance of 58 cm, with his or her head positioned in an adjustable head-and-chin rest. The words were 0.8-cm high and between 2.1- and 7.8-cm wide, displayed in Times New Roman font in white against a black background. Responses were made on a computer keyboard placed directly in front of the display screen. The "Q" and "9" keys (on the left of the top row of letters and on the right of the number pad, respectively) were used for responding.

2.1.3. Procedure

The experiment took place in a dimly lit, quiet room. The participant sat directly in front of the display screen. At the beginning of the session, s/he was shown the hand placement that would be used throughout the session. Half of the participants performed with the left index finger placed on the left key and the right index finger on the right key (uncrossed-hands placement). The other half placed the right index finger on the left key and the left index finger on the right key, with the right arm placed over the left arm (crossed-hands placement).

Each participant performed two trial blocks, one with the positive words mapped to the right hand and the negative words to the left hand (hand-congruent mapping), and the other with the positive words mapped to the left hand and the negative words to the right hand (hand-incongruent mapping), although the instructions were in terms of response keys. Half of the participants in each hand-placement group performed the first block with the mapping for which the "Q" ("9") key was to be pressed to a positive (negative) word and the "9" ("Q") key to a negative word, whereas half performed with the opposite mapping. In the second block, each participant received the mapping that was opposite of that in the first block. Each of the two trial blocks consisted of 24 practice trials and 120 test trials. The same stimulus set was used in both blocks; each word occurred three times within each block, with the order being randomized for each participant.

Participants were told that their task was to classify each word as positive or negative by pressing the assigned left or right response key. Prior to each trial block, the mapping for that block was described. Each trial started with a fixation cross (1.3 cm × 1.3 cm), which appeared in the center of the screen for 400 ms. At its offset, the stimulus was displayed, centered at the same location, until a response was made or for 2 s. Participants were to respond as quickly and accurately as possible during this period. After stimulus offset, a blank screen was shown for 1500 ms. On incorrect trials, a 400-Hz tone was presented for 500 ms, followed by a blank screen for 1000 ms. During practice trials, visual feedback "correct" or "incorrect" was presented, with the latter accompanied by the tone. For trials on which participants did not respond before 2 s, a message was shown for 500 ms prior to the blank screen: During practice it was "Please respond quickly"; during test it was "No response detected".

2.2. Results

Trials with RT < 200 ms or > 1500 ms were excluded from analysis (1.9% of all trials). Four participants with percent correct (PC) < 90% were replaced. Mean RT for correct responses and PC were computed for each participant. In accordance with what Barr, Levy, Scheepers, and Tily (2013) call the gold standard for analyses of studies in which both participants and items are random factors, maximal linear mixed-effect models (LMEMs) were built with RTs and PEs as separated dependent measures, and valence (with deviation coding positive: 0.5 or negative: −0.5), response hand (left: −0.5 or right: 0.5), hand placement (crossed: 0.5 or uncrossed: −0.5), and their interactions as fixed factors. By-subject and by-item intercepts were also included, as well as by-subject slopes for valence and response hand, and by-item slopes for response hand and hand placement (Barr et al., 2013). Analyses were conducted with the lme4 package (Bates, Maechler, & Bolker, 2011) for the R statistical environment, and significance values were estimated from the *t* values that were obtained from the lmer function.

The mean values for all conditions are shown in Table 1. For RT, the LMEM analysis showed the following significant effects. The main effect of response hand [$t(156) = 2.19$, $p = 0.030$, $SEM = 6.39$] reflected that right-hand responses ($M = 748$ ms) were 8 ms faster than the left-hand responses ($M = 756$ ms). The valence × response hand interaction [$t(2359) = -4.48$, $p < 0.001$, $SEM = 8.67$] indicated a mapping effect: RT was 29 ms shorter for the positive → right-hand/negative → left-hand mapping ($M = 737$ ms) than for the positive → left-hand/negative → right-hand mapping ($M = 766$ ms). The 3-way interaction involving valence, response hand, and hand placement was significant [$t(6079) = -2.15$, $p = 0.032$, $SEM = 12.20$], but this effect was not strong as it was not evident in a more conservative min F' analysis (Clark, 1973; Raaijmakers, Schrijnemakers, & Gremmen, 1999; Rietveld & van Hout, 2007), where min $F' < 1$. The mapping effect was significant for both the crossed-hands placement ($M = 33$ ms) [$t(773.2) = -7.47$, $p < 0.001$, $SEM = 8.71$] and the uncrossed-hands placement ($M = 25$ ms) [$t(2670.2) = -4.49$, $p < 0.001$, $SEM = 8.63$], though it was slightly larger with the hands crossed.

The analysis of PC did not show any significant effects at the 0.05 level.

2.3. Discussion

We obtained a similar effector-dependent effect as that reported by de la Vega et al. (2013) and showed that the benefit for the hand-congruent mapping was at least as large when the hands were crossed as when they were uncrossed. The similarity of effect magnitude for the crossed- and uncrossed-hands placements provides no indication of a contribution of response-location coding. Thus, the results are consistent with the view that the mapping preference for right-handed

Table 1
Mean response time in milliseconds and percent correct as a function of valence, hand placement, and response hand in experiment 1.

Placement/valence	Response time		Percent correct	
	Left hand	Right hand	Left hand	Right hand
Uncrossed				
Positive	747 (14.4)	715 (14.3)	95.9 (0.6)	95.6 (0.6)
Negative	734 (13.9)	751 (15.7)	95.7 (0.6)	95.4 (0.6)
Crossed				
Positive	780 (14.4)	739 (14.3)	94.9 (0.6)	94.2 (0.6)
Negative	762 (13.9)	786 (15.7)	96.0 (0.6)	95.5 (0.5)

Note: Standard error of the mean in parentheses.

persons is one of positive affect to right hand and negative affect to left hand (or of the spaces in which those hands are located), rather than one of positive and negative affect to right and left response keys. Moreover, this mapping preference was obtained without the inclusion of the additional no-go trials that de la Vega et al. used in their study, indicating that the complexity they added to the task was not a critical factor.

3. Experiment 2

In Experiment 2, left-handed participants performed the same valence-judgment task as the right-handed participants did in the crossed-hands condition of Experiment 1. Because of the reversal in dominant hand from Experiment 1, the body-specificity hypothesis predicts the opposite result pattern of faster responses with the mapping positive stimuli to left hand and negative stimuli to right hand than with the opposite mapping.

3.1. Method

3.1.1. Participants

A total of 20 new left-handed undergraduate students from the same subject pool as in Experiment 1 participated with the crossed-hands placement. This smaller sample size was necessitated by the lack of availability of many left-handed individuals. Handedness values on the Edinburgh inventory were $M = -49.9$; range: -10 to -85, with mean age of 19.6 years ($SD = 2.0$). As in Experiment 1, all participants were native English speakers and naïve to the purpose of the study. All reported having normal or corrected-normal vision and normal hearing.

3.1.2. Stimuli, apparatus, and procedure

The linguistic stimuli were the same materials used in the previous experiment. The apparatus and the procedure were the same as used in Experiment 1under crossed hand conditions, with exception that the left hand was crossed over the right hand since it was the dominant hand for these participants.

3.2. Results and discussion

The same outlier procedure as in Experiment 1 was conducted: Trials with RT < 200 ms or > 1500 ms were excluded from subsequent analyses (2.4% of all trials). One participant with PC < 90% was replaced. Mean RT for correct responses and PC were computed for each participant. A similar LMEM as in Experiment 1 was built with RT and PE as separate dependent measures, except that hand placement was not included in the model because all participants crossed their hands in this experiment.

For RT, the main effect of valence was not significant [$t < 1$]. Response hand showed a significant main effect [$t(42.4) = 3.72$, $p < 0.001$, $SEM = 9.70$], with right-hand responses ($M = 731$ ms) being 13 ms faster than left-hand responses ($M = 744$ ms). Most important, the valence × response hand interaction [$t(1233.3) = 4.30$, $p < 0.001$, $SEM = 11.17$] indicated that RT was 25 ms shorter for the positive → left-hand/negative → right-hand mapping ($M = 725$ ms) than for the positive → right-hand/negative → left-hand mapping ($M = 750$ ms).

For PC, no effects, including the valence × response hand interaction, were significant ($ts < 1$).

To examine the role of handedness across the experiments, we conducted combined analyses of RT for the crossed-hands conditions of Experiments 1 and 2, with experiment (handedness) as a factor in addition to valence and response hand. Of most interest are the terms involving experiment/handedness, which we report. There was no experiment main effect, $t < 1$, but the experiment × valence interaction was significant [$t(90) = 2.95$, $p = 0.004$, $SEM = 12.32$], with the valence effect being larger in Experiment 1 (Ms = 759 vs. 774 ms for positive and negative words, respectively) than in Experiment 2 (Ms = 739 vs. 736 ms for positive and negative words, respectively). The experiment × response hand interaction [$t(164) = 5.47$, $p < 0.001$, $SEM = 11.39$] was also significant, with the response-hand difference being smaller in Experiment 1 (Ms = 771 vs. 762 ms for left and right hands, respectively) than in Experiment 2 (Ms = 744 vs. 731 ms for left and right hands, respectively). Of most importance, the 3-way interaction of experiment (handedness) × valence × response hand was significant [$t(4508) = -7.79$, $p < 0.001$, $SEM = 14.54$], reflecting the opposite patterns in the two experiments. Therefore, the results are in agreement with the prediction of the body-specificity hypothesis that, for both right- and left-handed persons, the mapping of positive to dominant hand and negative to subordinate hand should have an advantage over the alternative mapping even when the hands are crossed.

4. Experiment 3

In the crossed-hands conditions of Experiments 1 and 2, the dominant hand was placed over the subordinate hand. This placement, rather than hand dominance, could have accounted for the opposite pattern of results for right- and left-handers in Experiments 1 and 2. To assess this possibility, we returned to the more accessible right-handed participants in Experiment 3 but had them perform with their subordinate left hand on top. According to the body-specificity hypothesis, whether the dominant hand is above or below the subordinate hand should not matter, and the same mapping preference should be found as in Experiment 1.

4.1. Method

4.1.1. Participants

A total of 40 new undergraduate students from the same subject pool as in Experiment 1 participated using the crossed-hands placement. Handedness values on the Edinburgh inventory were $M = +72.6$; range: $+45$ to $+100$, with mean age of 20.5 years ($SD = 1.7$). As in the other experiments, all participants were native English speakers and naïve to the purpose of the study. All reported having normal or corrected-normal vision and normal hearing.

4.1.2. Stimuli, apparatus, and procedure

The linguistic stimuli as well as the apparatus and the procedure were the same as used in Experiments 1 and 2, except for the hand location, for which the non-dominant arm (left) was placed on top of the dominant arm (right).

4.2. Results and discussion

The same outlier procedure as in Experiments 1and 2 was conducted: Trials with RT < 200 ms or > 1500 ms were excluded from analysis (2.1% of all trials). Three participants with PC < 90% were replaced. Mean RT for correct responses and PC were computed for each participant and are given in Table 2. The same analysis was conducted as in Experiment 2.

For RT, the only significant effect was the valence × response hand interaction [$t(1552.8) = -4.79$, $p < 0.001$, $SEM = 8.95$]: Mean RT was 25 ms shorter for the positive → right-hand/negative → left-hand mapping ($M = 780$ ms) than for the opposite mapping ($M = 805$ ms), similar to the 33-ms difference in Experiment 1.

For PC, no effects, including those involving valence × response hand ($ts < 1$), were significant.

To test whether placing the dominant hand over the subordinate hand, or vice versa, made a difference, we conducted combined analyses of RT for the crossed-hands conditions of Experiments 1 and 3, with experiment (hand location) as a factor in addition to valence and response hand. The valence × response hand interaction was still

Table 2
Mean response time in milliseconds and percent correct as a function of valence and response hand in Experiments 2 and 3 (which used crossed-hands placements).

Experiment/valence	Response time		Percent correct	
	Left hand	Right hand	Left hand	Right hand
Experiment 2				
Positive	733 (13.4)	745 (16.1)	94.7 (0.9)	93.9 (1.2)
Negative	755 (13.3)	717 (11.2)	94.9 (1.0)	94.6 (1.0)
Experiment 3				
Positive	811 (14.4)	765 (16.2)	97.3 (0.4)	96.6 (0.4)
Negative	795 (15.3)	799 (15.0)	97.5 (0.4)	96.6 (0.7)

Note: Standard error of the mean in parentheses.

significant [$t(884) = -4.82$, $p < 0.001$, $SEM = 8.87$]. For the terms involving experiment, the experiment × response hand interaction was significant [$t(189) = 2.62$, $p = 0.009$, $SEM = 10.35$], with the difference between the two hands being smaller in Experiment 1 [$Ms = 771$ vs. 762 ms for left and right hands, respectively] than Experiment 3 [$Ms = 803$ vs. 782 ms for left and right hands, respectively]. The experiment × valence interaction was not significant [$t < 1$], nor was the 3-way interaction of experiment × valence × response hand [$t(6064) = -1.79$, $p = 0.073$, $SEM = 12.41$; min $F' < 1$], indicating that the valence × response hand interaction was similar for the two experiments. Therefore, the results are in agreement with the prediction of the body-specificity hypothesis that the mapping of positive to dominant hand and negative to subordinate hand should have an advantage over the alternative mapping even when the dominant hand was under the subordinate hand.

5. General discussion

Experiments 1 and 3 confirmed the finding of de la Vega et al. (2013) that, for right-handed participants responding with the hands crossed, RT is shorter with the mapping of positive words to right hand (left key) and negative words to the left hand (right key) than with the opposite mapping. They also showed that this effect was of similar size to that obtained when responding with the hands in a more natural uncrossed position, for which the response hand and the position of the response key are in concordance. Thus, these results imply that the mapping effect for positive and negative words to left and right responses is due to the relation to left and right hands and not to the relation to left and right response keys. In other words, the effect reflects hand coding rather than spatial coding, as concluded by de la Vega et al. (2013).

If the results of Experiments 1 and 3 reflect a difference between the dominant and subordinate hands, then left-handed individuals would be expected to respond faster with the mapping of positive stimuli to left hand and negative stimuli to right hand than with the opposite mapping. The results of Experiment 2 showed that this was indeed the case for left-handed participants who performed with the crossed-hands placement. Thus, the results of our experiments imply, in agreement with the prediction of the body-specificity hypothesis, that the mapping advantage for positive and negative words mapped to responses on the left and right hands is in fact due to hand dominance.

A question is why the results with classification of words as positive/negative show evidence of coding with respect to dominant hand, whereas most results from spatial SRC and Simon effect studies show spatial coding with respect to the response keys to predominate (Proctor & Vu, 2006). One possibility is that there is something unique about the mapping between the valence of the word stimuli and the hands, and people associate their dominant hand with positive words, as proposed by the body-specificity hypothesis (Casasanto, 2009). That is, "good" words with positive valence are associated with one's "good" hand or with the space in which it operates.

Another possibility is that the stimuli used in the present study and that of de la Vega et al. (2013) were verbal, rather than spatial. The only experiment directly relevant to this issue of which we are aware is that of Ghozlan (1998), who had right-handed participants respond with compatible and incompatible mappings of the location words *left* and *right* to left and right keys with the hands uncrossed or crossed. With the uncrossed placement, an SRC effect of 132 ms was evident; but with the crossed placement, the SRC effect was a nonsignificant −12 ms (i.e., the tendency was toward a benefit for the mapping of *right* and *left* to the respective hands). The data were not reported for individual stimulus and response locations, but Ghozlan interpreted the results as indicating that codes for left and right hands countered those for right and left response locations with the crossed placement, eliminating the advantage for the spatially compatible mapping. Thus, Ghozlan's study suggests that even when the implied spatial dimension of the words is horizontal, the coding of the hands as left or right contributes to task performance.

A similar finding exists for the spatial-numerical association of response codes (SNARC) effect, for which with an uncrossed-hands placement the mapping of smaller numbers to the left hand and larger numbers to the right hand yields faster responses than the opposite mapping. Wood, Nuerk, and Willmes (2006) included a crossed-hands condition and found, as in Ghozlan's (1998) study, no SNARC effect for visual number words or auditory number words, as well as for digits and dice faces. Like Ghozlan, they attributed the absence of effect with crossed hands to hand coding countering location coding. However, Dehaene, Bossini, and Giraux (1993, Experiment 6) conducted a similar experiment and found that the SNARC effect was a function of the response locations. When hands were crossed, the left hand responded faster to larger numbers and the right hand to smaller numbers. Consequently, Dehaene et al. reached the different conclusion that the SNARC effect does not depend on the left-right hand distinction but on "a more abstract representation of the left-right axis" (p. 384). Thus, the results from the SNARC task are mixed.

The Simon effect for irrelevant left-right stimulus location often shows an asymmetry, such that for right-handed persons the effect is larger for the right stimulus but for left-handed persons it tends to be larger for the left stimulus (Rubichi & Nicoletti, 2006; Tagliabue et al., 2007). Rubichi and Nicoletti had participants perform with the hands crossed and found that for both left- and right-handed persons the asymmetry followed the hand distinction, with the Simon effect being larger to the side at which the dominant hand was located. They attributed the larger spatial Simon effect for the dominant hand to attention being directed to that hand: "… an attentional bias originating from the field of operation of the dominant hand would be at the basis of the relationship between the asymmetry of the Simon effect and handedness" (p. 1059). However, Seibold, Chen, and Proctor (2016) reported evidence that the asymmetry is an artefact of calculating the Simon effect relative to the stimulus locations: For the stimulus located on the dominant-hand side the corresponding response is made with the faster dominant hand and the noncorresponding response with the slower subordinate hand, and this relation is reversed for the stimulus on the subordinate-hand side. When the RT advantage for the right-hand is removed from the Simon effect, that effect shows no asymmetry. So, the dominant hand does not produce a larger Simon effect.

Across all the above studies, the stimulus-response hands mapping overrules the stimulus-response keys mapping with the affective word classification task and the *left-right* word verbal SRC task, but yields mixed results with the SNARC task and surrenders to the stimulus-response keys mapping with the spatial Simon task. The varied results themselves across the different tasks are noteworthy, and research that identifies the controlling factors should provide insight into the how the environment and body are incorporated into task representations for making speeded choice reactions.

One issue to resolve is the extent to which the various SRC effects reflect processes associated with the content of the specific stimulus and response sets versus more general processes involved in relating stimuli to responses. The body-specificity hypothesis (Casasanto, 2011; Casasanto & Chrysikou, 2011) is an example of a view that leans toward the former – the more fluent dominant hand is associated with the property of "good". In contrast, the polarity coding principle (Proctor & Cho, 2006; Proctor & Xiong, 2015) is an example of the latter – asymmetric coding of stimuli and responses as + and − polarity is a general property of information processing that influences performance across a range of distinct stimulus and response sets for which conceptual or perceptual overlap (similarity) is absent (Kornblum & Lee, 1995). The body-specificity hypothesis is generally consistent with several types of studies (Casasanto, 2011; Casasanto & Chrysikou, 2011) and predicts the results of the present study. The polarity coding principle is generally consistent with correspondence effects from several binary choice tasks requiring left or right responses (Proctor & Cho, 2006; Proctor & Xiong, 2015), but predictions based on spatial coding of right and left responses are not consistent with the present results. An account in terms of hand dominance can accommodate the results in an ad hoc manner (de la Vega et al., 2013; Huber et al., 2015), but for such an account to be credible, a rationale for when and why responses will be coded with regard to hand dominance is needed, as are demonstrations of generalizability across stimulus dimensions other than affect.

6. Conclusion

Our experiments provide corroborating evidence that the explicit categorization task for words as positive or negative affect in a two-choice reaction task shows a hand-dominance effect: The mapping of positive affect to the dominant hand and negative affect to the subordinate hand is more compatible than the reversed mapping. This pattern of results is as predicted by the body-specificity hypothesis but it is also consistent with a variant of the polarity coding principle in which the dominant hand provides the salient, plus polarity response code. Clarifying the tasks that yield this dominant-hand effect as opposed to those that show spatial relations to be crucial is a task for future research.

Acknowledgements

Xiaolei Song was supported by a General Program of National Natural Science Foundation of China (31671147).

Appendix A. Stimulus words used in all experiments[a]

Positive words		Negative words	
Accurate	Musical[b]	Aggressive	Embarrassing
Affectionate[b]	Nice	Annoying	Evil
Benevolent	Noble	Bad[b]	Guilty
Careful	Objective	Rude	Irritable
Caressing[b]	Peaceful	Bossy	Malicious
Considerate	Polite	Broken	Miserly
Comfortable	Relaxed	Brutal	Noxious
Cordial	Resourceful[b]	Dishonest[b]	Presumptuous[b]
Frank	Sunny	Cynical	Rigid
Healthy	Tactful	Deadhearted	Sad[b]
Humane	Tidy	Deathly	Snobbish
Loyal	Trustworthy	Dreadful	Vain

[a] The words were English translations of "clearly positive" and "clearly negative" sets of German adjectives used by Eder and Rothermund (2008), which in turn were selected based on their evaluative norms from a standardized word pool (Schwibbe, Röder, Schwibbe, Borchardt, & Geiken-Pophanken, 1981). Three words were substituted to ensure positive and negative clarity: considerate, polite, and irritable for complacent, canny, and irascible, respectively.
[b] Words used in practice.

References

Anzola, G. P., Bertoloni, G. G., Buchtel, H. A., & Rizzolatti, G. G. (1977). Spatial compatibility and anatomical factors in simple and choice reaction time. *Neuropsychologia*, *15*, 295–302.
Barr, D. J., Levy, R., Scheepers, C., & Tily, H. J. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of Memory and Language*, *68*, 255–278.
Bates, D., Maechler, M., & Bolker, B. (2011). lme4: Linear mixed-effects models using S4 classes. R package version 0.999375-41. http://CRAN.R-Project.org/package=lme4.
Casasanto, D. (2009). Embodiment of abstract concepts: Good and bad in right- and left-handers. *Journal of Experimental Psychology: General*, *138*, 351–367.
Casasanto, D. (2011). Different bodies, different minds: The body specificity of language and thought. *Current Directions in Psychological Science*, *20*, 378–383.
Casasanto, D., & Chrysikou, E. G. (2011). When left is "right": Motor fluency shapes abstract concepts. *Psychological Science*, *22*, 419–422.
Clark, H. H. (1973). The language-as-fixed-effect fallacy: A critique of language statistics in psychological research. *Journal of Verbal Learning and Verbal Behavior*, *12*, 335–359.
Dehaene, S., Bossini, S., & Giraux, P. (1993). The mental representation of parity and number magnitude. *Journal of Experimental Psychology: General*, *122*, 371–396.
Eder, A. B., & Rothermund, K. (2008). When do motor behaviors (mis)match affective stimuli? An evaluative coding view of approach and avoidance reaction. *Journal of Experimental Psychology: General*, *137*, 262–281.
Ghozlan, A. (1998). Stimulus–response compatibility and position of the hands: Nonadditive effects. *Perceptual and Motor Skills*, *86*, 843–850.
Huber, S., Klein, E., Graf, M., Nuerk, H. C., Moeller, K., & Willmes, K. (2015). Embodied markedness of parity? Examining handedness effects on parity judgments. *Psychological Research*, *79*, 963–977.
Kornblum, S., & Lee, J. W. (1995). Stimulus-response compatibility with relevant and irrelevant stimulus dimensions that do and do not overlap with the response. *Journal of Experimental Psychology: Human Perception and Performance*, *21*, 855–875.
Lenartowicz, A., Yeung, N., & Cohen, J. D. (2011). No-go trials can modulate switch cost by interfering with effects of task preparation. *Psychological Research*, *75*, 66–76.
Lu, C.-H., & Proctor, R. W. (1995). The influence of irrelevant location information on performance: A review of the Simon and spatial Stroop effects. *Psychonomic Bulletin & Review*, *2*, 174–207.
Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia*, *9*, 97–113.
Proctor, R. W., & Cho, Y. S. (2006). Polarity correspondence: A general principle for performance of speeded binary classification tasks. *Psychological Bulletin*, *132*, 416–442.
Proctor, R. W., & Shao, C. (2010). Does the contribution of stimulus-hand correspondence to the auditory Simon effect increase with practice? *Experimental Brain Research*, *204*, 131–137.
Proctor, R. W., & Vu, K.-P. L. (2006). *Stimulus-response compatibility principles: Data, theory, and application*. Boca Raton, FL: CRC Press.
Proctor, R. W., & Xiong, A. (2015). Polarity correspondence as a general compatibility principle. *Current Directions in Psychological Science*, *24*, 446–451.
Raaijmakers, J. G., Schrijnemakers, J., & Gremmen, F. (1999). How to deal with "the language-as-fixed-effect fallacy": Common misconceptions and alternative solutions. *Journal of Memory and Language*, *41*, 416–426.
Rietveld, T., & van Hout, R. (2007). Analysis of variance for repeated measures designs

with word materials as a nested random or fixed factor. *Behavior Research Methods*, *39*, 735–747.

Riggio, L., Gawryszewski, L. G., & Umiltà, C. (1986). What is crossed in crossed-hand effects? *Acta Psychologica*, *62*, 89–100.

Roswarski, T., & Proctor, R. W. (2000). Auditory stimulus–response compatibility: Is there a contribution of stimulus–hand correspondence? *Psychological Research*, *63*, 148–158.

Rubichi, S., & Nicoletti, R. (2006). The Simon effect and handedness: Evidence for a dominant-hand attentional bias in spatial coding. *Perception & Psychophysics*, *68*, 1059–1069.

Schwibbe, M., Röder, K., Schwibbe, G., Borchardt, M., & Geiken-Pophanken, G. (1981). Zum emotionalen Gehalt von Substantiven, Adjektiven und Verben[The emotional contents of nouns, adjectives, and verbs]. *Zeitschrift für Experimentelle und Angewandte Psychologie*, *28*, 486–501.

Seibold, J., Chen, J., & Proctor, R. W. (2016). Exploring handedness asymmetries in the Simon effect. *Attention, Perception, & Psychophysics*, *78*, 437–451.

Simon, J. R. (1990). The effects of an irrelevant directional cue on human information processing. In R. W. Proctor, & T. G. Reeve (Eds.), *Stimulus-response compatibility: An integrated perspective* (pp. 31–86). (Amsterdam: North-Holland).

Tagliabue, M., Vidotto, G., Umiltà, C., Altoè, G., Treccani, B., & Spera, P. (2007). The measurement of left/right asymmetries in the Simon effect: A fine-grained analysis. *Behavior Research Methods*, *39*, 50–61.

de la Vega, I., de Filippis, M., Lachmair, M., Dudschig, C., & Kaup, B. (2012). Emotional valence and physical space: Limits of interaction. *Journal of Experimental Psychology: Human Perception and Performance*, *38*, 375–385.

de la Vega, I., Dudschig, C., De Filippis, M., Lachmair, M., & Kaup, B. (2013). Keep your hands crossed: The valence-by-left/right interaction is related to hand, not side, in an incongruent hand–response key assignment. *Acta Psychologica*, *142*, 273–277.

Wallace, R. J. (1971). S-R compatibility and the idea of a response code. *Journal of Experimental Psychology*, *88*, 354–360.

Wood, G., Nuerk, H., & Willmes, K. (2006). Crossed hands and the SNARC effect: A failure to replicate Denhaene, Bossini and Giraux (1993). *Cortex*, *42*, 1060–1079.

Zhang, Y., Proctor, R. W., & Wegner, D. T. (2012). Approach-avoidance actions or categorization? A matching account of reference valence effects in affective S-R compatibility. *Journal of Experimental Social Psychology*, *48*, 609–616.