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## **Sharing a Mental Number Line Across Individuals?**

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**Sharing a Mental Number Line Across Individuals?  
The Role of Body Position and Empathy in Joint Numerical  
Cognition**

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Running head: JOINT NUMERICAL COGNITION

1  
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11 **Sharing a Mental Number Line Across Individuals?**  
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13 **The Role of Body Position and Empathy in Joint Numerical Cognition**  
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## JOINT NUMERICAL COGNITION

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## Abstract

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5 A growing body of research shows that the human brain acts differently when performing a  
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7 task together with another person than when performing the same task alone. In this study we  
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9 investigated the influence of a co-actor on numerical cognition using a joint random number  
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11 generation task (RNG). We found that participants generated relatively smaller numbers when  
12  
13 they were located to the left (vs. right) of a co-actor (Experiment 1), as if the two individuals  
14  
15 shared a mental number line and predominantly selected numbers corresponding to their  
16  
17 relative body position. Moreover, the mere presence of another person on the left or right side,  
18  
19 or the processing of numbers from loudspeaker on the left or right side had no influence on  
20  
21 the magnitude of generated numbers (Experiment 2), suggesting that a bias in RNG only  
22  
23 emerged during interpersonal interactions. Interestingly, the effect of relative body position  
24  
25 on RNG was driven by participants with high trait empathic concern toward others, pointing  
26  
27 towards a mediating role of feelings of sympathy for joint compatibility effects. Finally, the  
28  
29 spatial bias emerged only after the co-actors swapped their spatial position, suggesting that  
30  
31 joint spatial representations are constructed only after the spatial reference frame became  
32  
33 salient. In contrast to previous studies, our findings cannot be explained by action co-  
34  
35 representation because the consecutive production of numbers does not involve conflict at the  
36  
37 motor response level. Our results therefore suggest that spatial reference coding, rather than  
38  
39 motor mirroring, can determine joint compatibility effects. Our results demonstrate how  
40  
41 physical properties of interpersonal situations, such as the relative body position, shape  
42  
43 seemingly abstract cognition.  
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47  
48 *Keywords:* mental number line, random number generation, joint action, joint Simon  
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50 effect, empathy, Interpersonal Reactivity Index (IRI)  
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## JOINT NUMERICAL COGNITION

**Introduction**

Humans are a social species, and coordinated actions with other persons, such as carrying heavy objects or dancing, are an integral part of everyday life. Neuroscientists have started to realize that studying the human mind isolated from social contexts may be insufficient for a comprehensive understanding of cognitive processes. Several cognitive functions are shaped, or only exist, to allow inter-personal actions (van der Wel, Sebanz, & Knoblich, 2016). In the last decade, the research field of “joint action” has rapidly emerged and has started to unveil the neurocognitive principles of coordinated social actions (e.g., Novembre, Sammler, & Keller, 2016; Sebanz et al., 2006; Wriessnegger, Steyrl, Koschutnig, & Müller-Putz, 2016).

A seminal example of how brains work differently in joint (vs. single) tasks was provided by Sebanz, Knoblich, and Prinz (2003). In their study, two participants performed a joint reaction time task. Each participant controlled one of two response keys (left or right) and responded to a non-spatial stimulus dimension (red vs. green) of leftward or rightward pointing stimuli. Although the spatial information of the stimulus was task-irrelevant, there was a compatibility effect when the stimulus orientation corresponded to the side of response (i.e., a Simon effect; Simon, 1969). Crucially, such an effect was absent when each participant performed the identical single-key go-nogo task alone, showing that the spatial compatibility effect was the result of interacting with the co-actor. The authors concluded that a shared task representation and the integration of the co-actor’s action into one’s own action plan is crucial in joint action (Sebanz et al., 2003). The joint Simon effect has since been replicated and extended (Dolk et al., 2014).

The exact mechanism behind such joint compatibility effects is still under debate. On the one hand, it has been suggested that the cortical mirror neuron system plays a crucial role in this process by covertly simulating the co-actor’s action in the motor system (e.g., Gallese, Keysers, & Rizzolatti, 2004; Iacoboni et al., 2005). Accordingly, this motor simulation may

## JOINT NUMERICAL COGNITION

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3 drive the joint compatibility effect because it leads to a conflict for ‘go’ responses when the  
4 irrelevant spatial stimulus dimension primes the co-actor’s response (Atmaca, Sebanz, Prinz,  
5 & Knoblich, 2008; Sebanz et al., 2003). This suggestion is in line with *ideomotor theory*,  
6 claiming that anticipating another person’s motor response activates the same neuronal  
7 structures as when the responses were self-generated (Hommel, Musseler, Aschersleben, &  
8 Prinz, 2001). On the other hand, it has been suggested that the spatial reference frame  
9 resulting from the co-representation of others’ actions is the crucial aspect (Dolk et al., 2011;  
10 Guagnano, Rusconi, & Umiltà, 2010). Accordingly, the representation of the co-actor’s action  
11 provides a basis for coding one’s own actions relative to others. This account moves the focus  
12 away from the automatic co-representation of the co-actor’s stimulus-response rules to a more  
13 comprehensive view of referential event coding (Dolk et al., 2014), and implies that also  
14 one’s relative body position in space may play an important role for higher cognitive  
15 processes (cf. Mast, Preuss, Hartmann, & Grabherr, 2014).

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31 The aim of this study was to further assess the mechanisms underlying joint  
32 compatibility effects and particularly the role of body position in joint cognition by means of  
33 a joint number task. Numbers are cognitively represented along a ‘mental number line’, with  
34 small numbers on the left and larger numbers on the right side of space (Fischer & Shaki,  
35 2014). A frequently replicated observation is that left-sided responses are faster for small  
36 numbers and right-sided responses are faster for large numbers during number categorization  
37 tasks. This so-called SNARC (spatial-numerical association of response codes) effect  
38 (Dehaene, Bossini, & Giraux, 1993) also occurs when two persons share the task (Atmaca et  
39 al., 2008). In the present study we asked two persons to consecutively generate numbers as  
40 randomly as possible (RNG) while being located at a co-actor’s left or right side. Previous  
41 studies have established that the magnitudes of the ‘random’ numbers are sensitive to spatial  
42 manipulations. For example, participants generate smaller numbers during leftward than  
43 during rightward body motion (Hartmann, Grabherr, & Mast, 2012; Loetscher, Schwarz,  
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## JOINT NUMERICAL COGNITION

Schubiger, & Brugger, 2008). In contrast to the joint SNARC task by Atmaca et al. (2008), the RNG task is lacking the conflict in the motor response because there is no cue that primes the co-actor's action alternative. Consequently, a numerical bias induced by the participants' relative positions in space cannot be explained by action co-representation (and mirror neuron system) accounts but rather by spatial referential coding. Regarding the specific effect of body position on RNG, two conflicting predictions can be made based on previous work. First, a recent study reported that the co-actor influences the randomness of one's own number sequence during joint RNG (Towse, Towse, Saito, Maehara, & Miyake, 2016), showing that the co-actors verbal output cannot be ignored. Processing the verbal information of another person to one's left or right is accompanied by shifts in spatial attention: It has been documented that perceiving a (task-irrelevant) sound shifts spatial attention automatically towards the side of the sound (Mazza, Turatto, Rossi, & Umiltà, 2007; McDonald, Teder-Salejarvi, & Hillyard, 2000; Schmitt, Postma, & De Haan, 2000; Spence & Driver, 1997). Given the tight coupling between spatial attention in external space and representational number space (Fischer, Castel, Dodd, & Pratt, 2003; Longo & Lourenco, 2010; Zorzi, Priftis, & Umiltà, 2002), attentional shifts toward the co-actor are therefore likely to influence RNG. A first hypothesis places the focus on the attention directed toward the co-actor and predicts that smaller numbers will be selected by participants located to the right of another person because their leftward attentional shifts toward their co-actor make smaller numbers cognitively more available (and vice versa for participants located to the left of another person). A second and competing hypothesis places the focus on the spatial reference frame induced by the dyad and predicts that the person on the right side of the dyad would generate larger numbers than when being on the left side because the joint SNARC effect suggests that processing larger numbers is facilitated when oneself is being located on the right side (Atmaca et al., 2008), or because of attentional withdrawal from the co-actor (Szpak et al., 2015; Szpak, Nicholls, Thomas, Laham, & Loetscher, 2016).

## JOINT NUMERICAL COGNITION

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3 Yet another open issue in the field of joint action is the extent to which joint  
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5 compatibility effects are social in nature (Dolk et al., 2014). Since the accounts described so  
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7 far are based on the (co)representation of others, one would expect that social aspects play a  
8  
9 crucial role. In line with this view, several studies found that trait empathy of the actor  
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11 moderates joint action effects (Ford & Aberdein, 2015; Novembre, Ticini, Schütz-Bosbach, &  
12  
13 Keller, 2012), as does the quality of relationship between actors (Hommel, Colzato, & van  
14  
15 den Wildenberg, 2009) and the perceived similarity between the actors (Iani, Anelli, Nicoletti,  
16  
17 Arcuri, & Rubichi, 2011; Müller et al., 2011; Stenzel et al., 2012; Tsai, Kuo, Hung, & Tzeng,  
18  
19 2008). However, more recent studies ‘de-socialized’ joint compatibility effects by showing  
20  
21 that also non-social events, such as a Japanese waving cat or a ticking metronome, are  
22  
23 sufficient to influence individual task performance (Dolk et al., 2011; Dolk, Hommel, Prinz,  
24  
25 & Liepelt, 2013). These authors concluded that joint spatial compatibility effects result from  
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27 any salient event that serves as spatial reference for one’s own actions and are not necessarily  
28  
29 social. Following this conclusion, the role of social aspects in our RNG task should be  
30  
31 limited. In the present study, we measured participants’ trait empathy in order to further  
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33 examine the ‘social nature’ of the joint compatibility effect. If the integration of another  
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35 person into one’s own task representation is the crucial mechanism, then the spatial  
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37 compatibility effect should be more pronounced for participants with high empathy (Ford &  
38  
39 Aberdein, 2015; Novembre et al., 2012).

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44 Finally, we assessed the role of the position change for the spatial compatibility effect.  
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46 Participants changed their spatial position with the co-actor halfway through the experiment,  
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48 so that each participant generated numbers from the left and right side relative to their co-  
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50 actor. Comparing the spatial compatibility effect before and after the position change will  
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52 reveal whether the effect automatically occurs upon sharing a task, or conditionally only after  
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54 the spatial frame of reference has been made salient by a spatial event (e.g., position change).

**Experiment 1**



## Method

**Participants.** Sixty-eight persons took part in Experiment 1 (48 female). The mean age was 25.4 years ( $SD = 11, 5$ ). The sample consisted of undergraduate students ( $n = 60$ ) and other persons from the private environment of the experimenter ( $n = 8$ ). Participants gave written informed consent prior to the study. The study was approved by the local Ethics Committee.

**Task and Procedure.** In line with previous studies, participants were instructed to verbally state a sequence of numbers in the range of 1-30 as randomly as possible (Loetscher et al., 2008). Half of the participants ( $n = 34$ ) performed the RNG task in a joint condition and the other 34 in a single condition. In a previous study, effects of empathy have only been found for actors that knew each other (Ford & Aberdein, 2015). We therefore decided to only investigate pairs of participants that were already acquainted. Participants who performed the RNG task in the joint condition were therefore recruited pairwise (they were acquainted by self report and considered themselves as colleagues or friends). In the joint condition, the two participants were seated next to each other in front of a table (see Figure 1). The starting positions (left, right) were randomly assigned to the participants within each pair prior to the experiment. Participants were instructed to alternatingly state random numbers at the pace of a metronome (0.66 Hz, presented by an ordinary laptop that was placed at the middle of the table). Participants were told to focus on the randomness of the own sequence and ignore the numbers of the co-actor. After each participant had stated 40 numbers, they switched their position and alternatingly stated another 40 numbers each. In the single condition, one participant stated 40 numbers sitting alone on one side of the table, followed by another sequence of 40 numbers sitting on the other side of the table (see Figure 1). Half of participants in the single condition started on the left, and the other half on the right side of the table. In order to mimic the characteristics of the joint condition, the laptop was placed next to the participant on top of a box on the empty chair, approximately at the position where

## JOINT NUMERICAL COGNITION

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3 the head of the co-actor would be. This was done in order to evaluate whether any spatial bias  
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5 in the joint condition was induced by joining the task with the co-actor or rather by the non-  
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7 social spatial frame of reference employed in this study (i.e., sitting on the left or right side of  
8  
9 a table, hearing a sound from one's left or right side). Moreover, the pace of the metronome  
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11 was set to 0.33 Hz, so that the frequency of generated numbers in the single condition was  
12  
13 identical to the one of the individual sequence in the joint condition.  
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16 [Insert Figure 1 here]  
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20 During the experiment, the experimenter took place behind the participants (thus  
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22 outside of their view), in a position centrally aligned to the table. In both conditions,  
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24 participants were facing straight ahead and closed their eyes during RNG. Numbers were  
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26 written down by the experimenter during the experiment, and they were also recorded by  
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28 means of Audacity (run on the same laptop as the metronome sound). All numbers were  
29  
30 checked offline by a person blind to the hypothesis.  
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32

33 After the random number generation task, participants filled out a personality  
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35 questionnaire (see next section). At the end of the experiment, participants were asked to  
36  
37 guess the aim of the experiment.  
38

39 **Assessment of Empathy.** Trait empathy was measured using the Interpersonal  
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41 Reactivity Index (IRI) (Davis, 1983). The IRI assumes that empathy consists of a set of four  
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43 separate but related constructs: empathic concern, perspective taking, fantasy scale, and  
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45 personal distress. *Empathic concern* captures one's tendency to experience feelings of  
46  
47 sympathy and compassion for unfortunate others. Empathic concern does not simply reflect  
48  
49 the sharing of emotional states with others but rather the internal state of emotion and  
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51 motivation driven by the concern for another person's welfare (e.g., Bernhardt & Singer,  
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53 2012). *Perspective taking* captures one's tendency to adopt the point of view of others.  
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55 Finally, *fantasy scale* focuses on one's tendency to imaginatively transpose the self into  
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## JOINT NUMERICAL COGNITION

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3 fictional situations, and *personal distress* on one's tendency to experience distress in  
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5 emotional situations. We used the German version of the IRI (Paulus, 2009). The  
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7 questionnaire consists of 16 questions (4 for each subscale), and responses were given on a 5-  
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9 point Likert scale ranging from 1 = never to 5 = always. Participants used the online version  
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11 of the questionnaire ([http://bildungswissenschaften.uni-](http://bildungswissenschaften.uni-saarland.de/personal/paulus/empathy/SPF_SE.html)  
12  
13 [saarland.de/personal/paulus/empathy/SPF\\_SE.html](http://bildungswissenschaften.uni-saarland.de/personal/paulus/empathy/SPF_SE.html)) and the scores were automatically  
14  
15 computed online and stored by the experimenter.  
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**Results and Discussion**

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20 Data from one pair of participants in the joint condition and from two participants in  
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22 the single condition was excluded from analysis because they did not follow task instruction  
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24 (they generated obviously non-random sequences such as 2, 4, 6, 8 and so on). None of the  
25  
26 participants guessed the hypothesis of this experiment.  
27

28  
29 **The Role of Body Position.** For each of the remaining 64 participants, the mean of  
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31 generated numbers for each body position (left, right) was analyzed by a mixed-model  
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33 analysis of variance (ANOVA) with the within-subject variable position (left, right) and the  
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35 between-subject variable condition (joint, single). There was a significant main effect of  
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37 position,  $F(1, 62) = 6.17, p = .016, \eta^2_p = .09$ . Overall, the mean of numbers generated on the  
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39 left was lower than the mean of numbers generated on the right ( $M_{\text{left}} = 14.5, SD = 1.5; M_{\text{right}}$   
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41  $= 14.9, SD = 1.3$ ). There was no main effect of condition,  $F(1, 62) = 0.71, p = .403, \eta^2_p = .01$   
42  
43 ( $M_{\text{joint}} = 14.6, SD = 1.3; M_{\text{single}} = 14.9, SD = 1.3$ ). Most importantly, the two variables  
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45 interacted,  $F(1, 62) = 5.83, p = .019, \eta^2_p = .09$ . Post hoc tests (paired *t*-tests) revealed a  
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47 significantly lower mean of generated numbers when participants were sitting on the left than  
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49 on the right side in the joint condition ( $p = .002; M_{\text{left}} = 14.2, SD = 1.5; M_{\text{right}} = 14.9, SD =$   
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51  $1.3$ ), while there was no effect of body position in the single condition ( $p = .959, M_{\text{left}} = 14.8,$   
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53  $SD = 1.6; M_{\text{right}} = 14.8, SD = 1.3$ ; see Figure 2).  
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[Insert Figure 2 here]

**The Role of Empathy.** The mean empathy scores for the four sub-scales was similar in both conditions (see Table 1). Independent  $t$ -tests confirm that there was no difference in the sub-scales between the two groups (all  $ps > .273$ ). In order to assess a possible role of empathy for the influence of body position on RNG, empathy scores of participants in the joint condition were correlated with the individual difference between the averages of numbers generated on the right and left side ( $RNG_{Diff} = M RNG_{right} - M RNG_{left}$ ). Positive  $RNG_{Diff}$  values indicate that higher average numbers were stated in the right (vs. left) position. There was a significant positive correlation for the subscale empathic concern (see Table 1). In order to further characterize the relationship between empathic concern and the spatial bias in RNG, participants were allocated to a low or high empathic concern group, based on the median split (median = 15). Four participants had a score of 15 (median) and were excluded from this analysis. The mean empathic concern score of the *high* group ( $n = 14$ ) was 16.8, ranging from 16-20 ( $SD = 1.3$ ), and the mean score of the low group ( $n = 14$ ) was 12.4, ranging from 9-14 ( $SD = 1.7$ ). Separate paired  $t$ -tests with the within-subject variable body position revealed a significant effect of body position only for the high empathic concern group,  $t(13) = 4.26$ ,  $p = .001$ ,  $M RNG_{Diff} = 1.1$  ( $SD = 1.0$ ), but not for the low empathic concern group,  $t(13) = 0.24$ ,  $p = .814$ ,  $M RNG_{Diff} = 0.1$  ( $SD = 1.2$ ).

[Insert Table 1 here]

**The Role of Position Change.** The analysis of body position revealed an effect of body position on the magnitude of generated numbers in the joint condition. We further analyzed this effect in order to explore whether the change in position was relevant for the emergence of the spatial bias. We conducted another ANOVA with the variables position (left, right) and position chance (before, after) for the joint condition. There was a main effect

## JOINT NUMERICAL COGNITION

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3 of position (as reported above) but no main effect of position change,  $F(1, 60) = 0.11, p =$   
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5  $747, \eta^2_p < .01$ . Interestingly, these variables interacted,  $F(1, 60) = 5.77, p = .019, \eta^2_p < .09$ .  
6  
7 Post-hoc tests (independent-samples  $t$ -tests) revealed that there was no difference between the  
8  
9 left and right position *before* co-actors changed positions,  $t(30) = -0.09, p = .927$  ( $M_{\text{left}} = 14.5,$   
10  
11  $SD = 0.3; M_{\text{right}} = 14.5, SD = 0.3$ ), but there was a significant difference *after* co-actors  
12  
13 changed positions,  $t(30) = -3.11, p = .004$  ( $M_{\text{left}} = 13.9, SD = 0.3; M_{\text{right}} = 15.3, SD = 0.3$ ).  
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16 We also compared the mean magnitude of numbers between the left and right position  
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18 after the the change in position for the single condition (by means of an independent sample  $t$ -  
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20 test). There was no effect of position in the single condition after the change in position,  $t(30)$   
21  
22  $= 0.31, p = .760$  ( $M_{\text{left}} = 14.9, SD = 1.4; M_{\text{right}} = 14.7, SD = 1.7$ ).  
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25

26 [Insert Figure 3 here]  
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29 The results so far point to a modulation of numerical cognition due to the construction  
30  
31 of a spatial reference between the actor and the co-actor. Particularly, the actor seems to  
32  
33 represent him-or herself as being located on the left or right side of the co-actor, and this  
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35 biases the selection of numbers from the assumed mental number line (cf. Discussion).  
36  
37 However, the nature of the effect found in Experiment 1 sill remains open because it is  
38  
39 unclear whether the spatial bias was based on interpersonal interactions, or driven by the  
40  
41 salient events provided by the co-actor (i.e., producing numbers on the actor's left and right  
42  
43 sides). It has been argued that any salient event might lead to referential coding (Dolk et al.,  
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45 2014) and therefore might potentially induce a bias in RNG.  
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48 These considerations raise two further questions. First, is the joint task performance  
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50 with the other person mandatory for the bias in RNG, or does the *mere presence* of another  
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52 person suffice to serve as spatial reference? And second, does the co-actor need to be a human  
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54 being, or is the processing of numbers from one's left or right side (e.g. from a loudspeaker  
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56 instead of a human co-actor) sufficient to induce a bias in RNG? To address these questions, a  
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## JOINT NUMERICAL COGNITION

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3 second experiment was performed in which the actor generated numbers alternating with a  
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5 loudspeaker instead of a human co-actor. At the same time, another person was merely sitting  
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7 at the same position as the loudspeaker, serving as potential spatial reference point.  
8

**Experiment 2****Method**

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13 **Participants.** Twenty-four undergraduate students took part in Experiment 2 (17  
14  
15 female). The mean age was 22.6 years ( $SD = 1.7$ ). Participants gave written informed consent  
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17 prior to the study.  
18

19  
20 **Task and Procedure.** The procedure was identical to the joint condition from  
21  
22 Experiment 1 with the following two exceptions: First, the experimenter (instead of another  
23  
24 actor) took the place on the left or right side of participants. Second, participants did not  
25  
26 generate numbers in turn with a human co-actor. Instead, pre-recorded random numbers (see  
27  
28 below) were presented with a pace of 0.33 Hz through loudspeakers of a laptop that was  
29  
30 positioned on participant's left or right side (the laptop was placed on the table in front of the  
31  
32 experimenter). Thus, as in Experiment 1, participants stated numbers between 1-30 at an  
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34 individual pace of 0.33 Hz (guided by a 0.66 Hz metronome tick) but this time in alternation  
35  
36 with a "non-human co-actor". After participants had generated 40 numbers, they exchanged  
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38 their position with the experimenter (and laptop) and generated another 40 numbers. Half of  
39  
40 the participants started on the left, and the other half on the right side. In order to avoid any  
41  
42 confound between the position and the magnitude of the numbers played through  
43  
44 loudspeakers, two fixed pre-recorded number sequences (A and B) were used and  
45  
46 counterbalanced at each position. The two sequences were created by generating two random  
47  
48 sequences of 40 numbers from 1-30 ( $M_{\text{Sequence A}} = 14.7$ ,  $M_{\text{Sequence B}} = 14.5$ ) that were converted  
49  
50 to soundfiles using a text-to-speech application (<https://ttsreader.com>; German voice, average  
51  
52 duration of soundfiles = 633 ms). Half of the participants that started on the left side heard  
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## JOINT NUMERICAL COGNITION

Sequence A, followed by Sequence B after the change of position, and vice versa for the other half, and the same was true for participants that started on the right side.

**Results**

The mean magnitude of generated numbers was compared between the left and right position by means of a paired  $t$ -test. There was no effect of position,  $t(23) = 0.15$ ,  $p = .883$  ( $M_{\text{left}} = 14.9$ ,  $SD = 0.8$ ;  $M_{\text{right}} = 14.9$ ,  $SD = 0.9$ ). There was also no effect of position when only data after the change in position were considered,  $t(22) = -0.27$ ,  $p = .792$  ( $M_{\text{left}} = 14.8$ ,  $SD = 0.7$ ;  $M_{\text{right}} = 14.9$ ,  $SD = 0.7$ ).

**Discussion**

In this study we investigated the role of body position and empathy in joint numerical cognition. We found that the relative spatial position of a person influenced the magnitude of randomly generated numbers: Individuals generated smaller numbers when they were sitting to the left of another person, whereas they generated larger numbers when sitting to the right of another person. An influence of spatial body position (i.e., sitting on the left vs. right side of a table) was absent when participants performed the same task alone or with a non-human co-actor. Also, the mere presence of another person on the left or right side did not induce a bias in RNG, confirming that the bias observed in the joint condition can be attributed to the interaction with the other person. Interestingly, number magnitudes were not biased *toward* the co-actor's side, as one could expect due to attentional shifts along the mental number line (cf. Introduction). Rather, the observed pattern suggests that participants preferred to select numbers from the mental number line that spatially corresponded to their own physical body position relative to the other person, as if the two individuals were attending to different parts of a joint mental number line. This 'mental separation' from the co-actor might stem from a need for own space as a compensatory reaction to the personal space invasion in the joint condition (Terry & Lower, 1979). In fact, attentional shifts away from the other person have recently been related to social discomfort (Szpak et al., 2015). However, in the present study,

## JOINT NUMERICAL COGNITION

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3 individuals were acquainted, and the spatial bias was more pronounced for individuals with  
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5 higher empathic concern, suggesting that our results are rather the consequence of the  
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7 integration of the co-actor into a shared mental representation than attentional withdrawal  
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9 from the co-actor due to social discomfort.

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11 Our results are in line with the general idea of a shared task representation during joint  
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13 coordination (Sebanz et al., 2006). However, our results cannot be explained by action co-  
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15 representation: There was no priming of the co-actor's action and consequently no conflict  
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17 due to motor simulation of the co-actors action, as it was the case in previous studies (Atmaca  
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19 et al., 2008; Sebanz et al., 2003). Our results therefore suggest that joint compatibility effects  
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21 do not necessarily depend on motor mirroring mechanisms (Atmaca et al., 2008; Kuhbandner,  
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23 Pekrun, & Maier, 2010). Instead, spatial reference coding seems to be the crucial factor,  
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25 shaping the way how a task and the individual's and co-actor's contribution to that task are  
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27 represented.  
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31 The integration of one's own relative position into a numerical task does not seem to  
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33 happen automatically upon the initial sharing of a task. In this study, the spatial bias emerged  
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35 only after participants swapped their spatial positions. The act of changing positions may have  
36  
37 activated or augmented the spatial relationship between the actor and co-actor, allowing for  
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39 referential coding in the number selection process. This result is in line with the idea that a  
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41 salient spatial event, in this case a change in position, is important for referential coding (Dolk  
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43 et al., 2011; Dolk et al., 2013). Crucially, the change of position in the single condition  
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45 (Experiment 1), or the change of position with a passive person and a loudspeaker  
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47 (Experiment 2) is also likely to make the spatial frame of reference more salient. Particularly,  
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49 moving from one side of the table to the other may increase awareness of the spatial  
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51 relationship between the actor and the other spatial reference points of the experimental  
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53 situation (e.g., the empty chair, the side of table, the passive person, the loudspeaker).  
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55 However, no effect on number selection was observed in these cases. Thus, referential coding  
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## JOINT NUMERICAL COGNITION

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3 may depend on a salient reference point that emphasizes the spatial frame of reference of the  
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5 dyad, which (at least in this study) was induced only by joint task performance with a human  
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7 co-actor.

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9         Interestingly, the effect of relative body position on RNG was mainly driven by  
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11 participants with high empathic concerns toward others. This trait seems to boost the spatial  
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13 coding of oneself relative to others. A possible explanation would be that empathic concerns  
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15 toward others increase their salience as reference for own action/cognition (see Dolk et al.,  
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17 2014, for a similar argumentation). In contrast, the effect of body position was not related to  
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19 the other three sub-dimensions of empathy measured by the IRI. Personal distress and fantasy  
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21 scale do not directly capture sensitivity towards others in social situations (Paulus, 2009), and  
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23 the lack of correlation may not be too surprising. More intriguingly, there was no correlation  
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25 with perspective taking, which captures the ability to take other's viewpoints. This particular  
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27 ability has been shown to mediate effects of joint action in other contexts (Ford & Aberdein,  
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29 2015; Novembre et al., 2012), and a moderating role could also have been expected during  
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31 joint RNG (Towse et al., 2016). A possible explanation for the absence of an effect of  
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33 perspective taking might be that taking the viewpoint of the co-actor during RNG shifts the  
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35 focus of attention toward the co-actor's side of the mental number line. An effect of  
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37 referential coding on number selection may therefore be diluted for participants with a higher  
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39 tendency to adopt their co-actor's viewpoint. While the exact role of empathy still remains  
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41 open, this study points to a possible role of sympathy (i.e., the emotional and motivational  
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43 state driven by the concern for others) in addition to the cognitive aspect of empathy (i.e.,  
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45 perspective taking) in the modulation of joint action/cognition effects. However, it should be  
46  
47 noted that the correlation between empathic concern and the bias in RNG was only just  
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49 significant, and that the results of the spatial bias within the low and high empathic concern  
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51 groups (based on median split) was based on a limited sample size ( $n = 14$  per group). The  
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53 role of empathic concern therefore needs to be replicated in future studies. As a further  
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3 limitation of this study, it remains an open question whether a role of empathic concern is  
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5 exclusive for individuals that know each other (cf. Ford & Aberdein, 2015).  
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7         To our knowledge, joint compatibility effects have only been investigated in tasks  
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9 where participants needed to decide whether a response is required or not (go-nogo), or where  
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11 an explicit leftward or rightward spatial decision was required (Szpak et al., 2016). We  
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13 showed that joint compatibility effects generalize to turn-taking situations in which not the  
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15 decision to act, but rather the choice between seemingly arbitrary actions (i.e., which number  
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17 to choose) was biased by the interpersonal situation. Relatedly, previous research attributed  
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19 spatial compatibility effects to the spatial location of the response key (Welsh, 2009). We  
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21 showed that, when verbal responses are required, the individual's body position determines  
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23 the spatial reference frame (cf. Wenke et al., 2011).  
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26         To conclude, our results add to a growing body of research showing that the human  
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28 mind acts differently when a task is performed alone than when it is performed together with  
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30 another person. Our results suggest that spatial reference coding is a crucial mechanism that  
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32 underlies joint compatibility effects. The effect of relative body position is likely the result of  
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34 a more general tendency to construct a common representational space with egocentric  
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36 coordinates, which may serve as basis for any social interactions, and interestingly, also  
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38 shapes seemingly abstract cognitive processes such as number processing.  
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**Figure Captions**

Figure 1. Experimental procedure of the joint (left part) and single (right part) random number generation (RNG) task. Participants changed their position(s) after 40 numbers. Examples of numbers in this figure are random and their greyscale in the joint condition signals number originates with one or the other participant.

*Figure 2.* Mean of generated numbers during the random number generation task for the left and right body position in the joint and single conditions. The asterisk indicates a significant difference between the left and right position in the joint condition. Error bars depict  $\pm 1$  SEM.

*Figure 3.* Mean of generated numbers during the random number generation task for the left and right body position before and after the position change with the co-actor in the joint condition. The asterisk indicates a significant difference between the left and right position after the position change. Error bars depict  $\pm 1$  SEM.

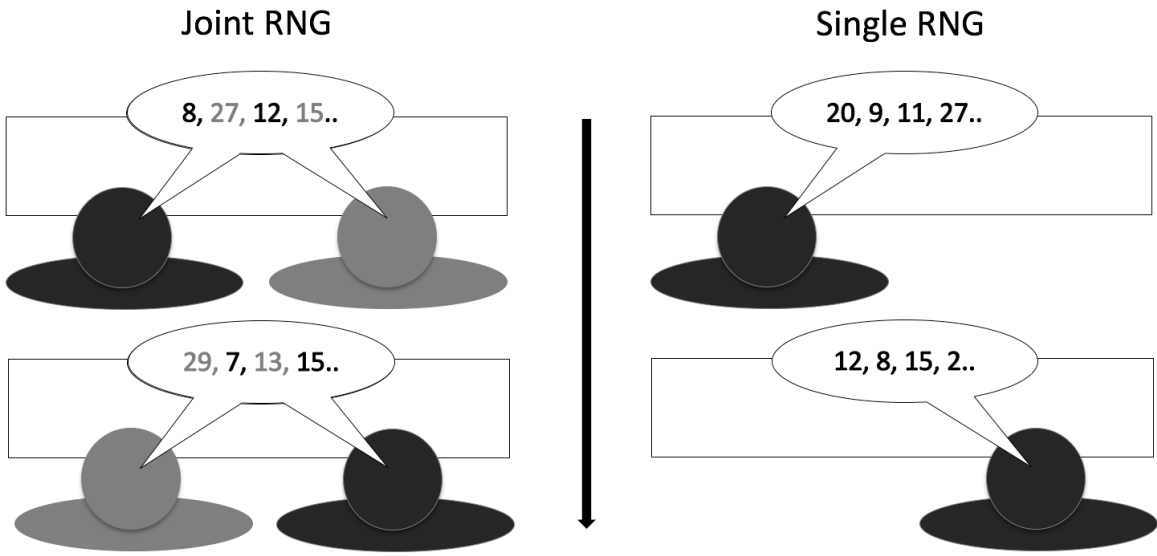
**Table 1**

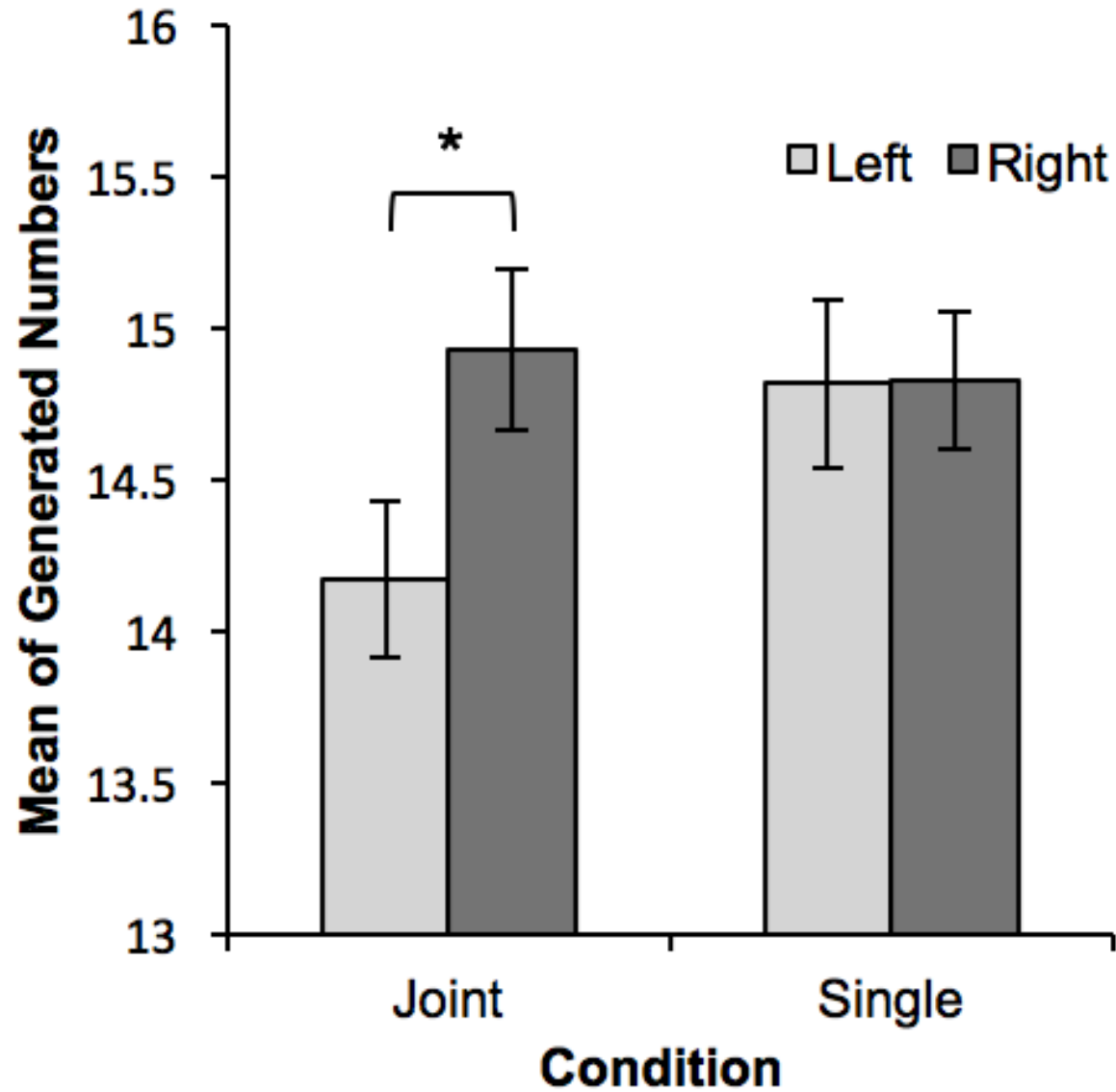
Mean empathy scores for the two experimental groups and correlations between the differences in RNG (right-left position) and empathy of participants in the joint condition

	Experimental Condition				Correlation between	
	Single ( $n = 34$ )		Joint ( $n = 32$ )		RNG <sub>Diff</sub> and Empathy	
Empathy	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>r</i>	<i>p</i>
Empathic concern	15.3	2.6	14.6	2.5	.370*	.037
Perspective taking	15.4	2.6	15.1	2.2	-.126	.491
Fantasy scale	13.5	3.5	13.4	2.4	.032	.864
Personal distress	11.3	2.5	10.8	2.9	.096	.601

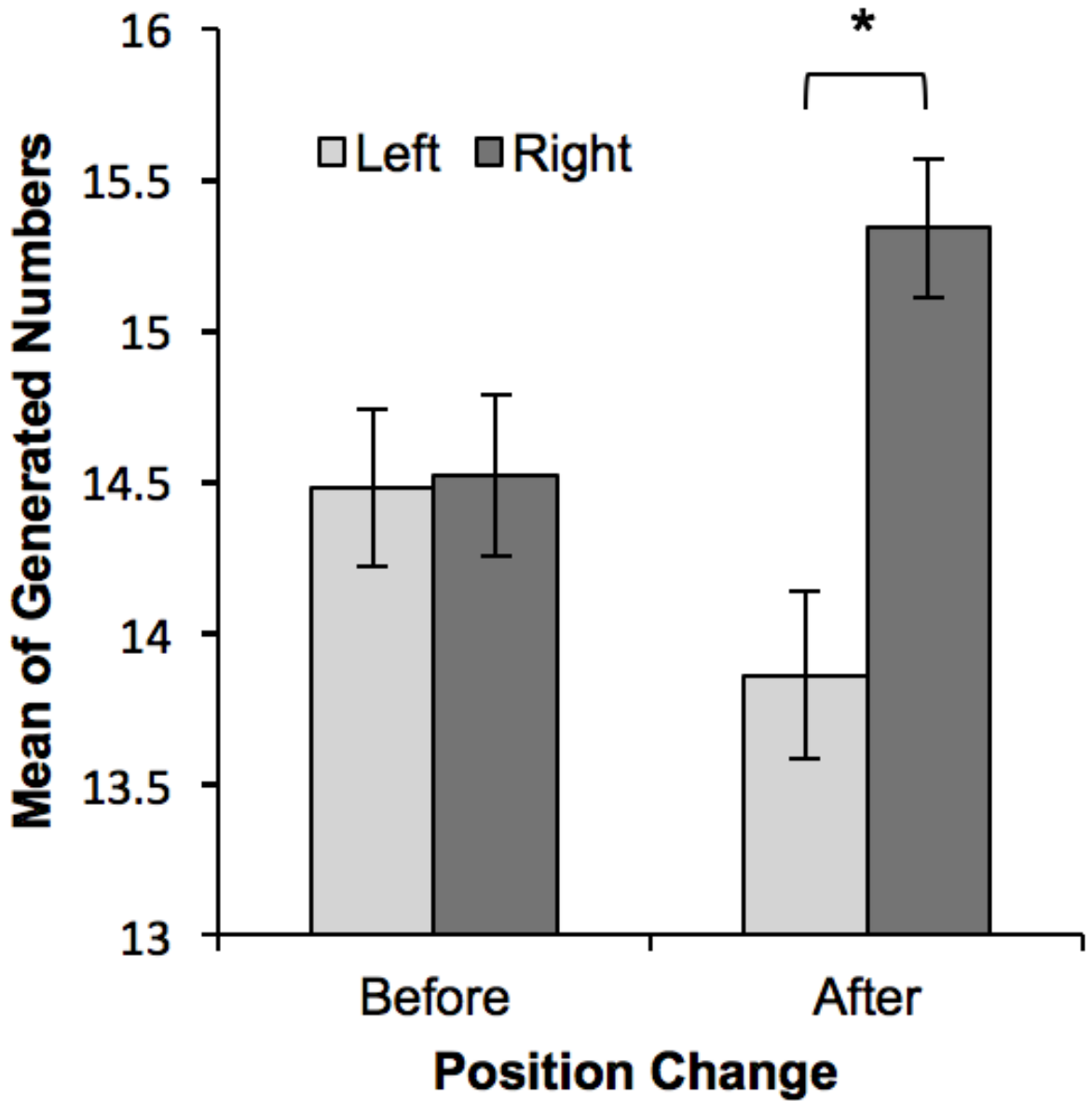
*Note.* *M* = mean (test score), *SD* = standard deviation, *r* = Spearman correlation between the difference in mean random numbers generated in the right and left spatial position (RNG<sub>Diff</sub> =  $M \text{ RNG}_{\text{right}} - M \text{ RNG}_{\text{left}}$ ) and empathy of participants in the joint condition.

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