

Conceptual Replication of “Compatibility between Physical Stimulus Size and Left-right  
Responses: Small is Left and Large is Right”

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## Abstract

The present study is a conceptual replication of experiment 1 from Wühr and Segeelke (2018) “Compatibility between Physical Stimulus Size and Left-right Responses: Small is Left and Large is Right”. We investigate stimulus-size-horizontal-response mapping compatibility effects by means of an online experiment. For example, Wühr and Segeelke (2018) found that participants in their experiment 1 were faster to respond to a large stimulus object with a key that is on the right of the keyboard (e.g. “Backspace”, pressed with the right hand), than with a key that is on the left of the keyboard (e.g. “Tabulator”, pressed with the left hand). For small stimulus objects, they found that reaction times were numerically faster for left-hand responses than for right-hand responses. Wühr and Segeelke (2018) consider their study’s results as in line with “A theory of magnitude” (ATOM), which was proposed by Walsh (2003), and as an extensions of the so called “SNARC”-effect for physical-size instead of numerical magnitudes. ATOM basically claims that there exist certain relations between the cortical representations of “time, space and quantity”, whereas the SNARC-effect is thought to demonstrate shared mental representations of magnitude in the form of number and horizontal locations in space (left vs. right hemifields). In this paper, we present findings from a sample of twice as many right-handed participants as in the original study, that deviate from the results of the original study by Wühr and Segeelke (2018), in that right-handed participants in the present study (N=57) responded more slowly to a small stimulus object with their left hand than to a large stimulus object. Additionally, when presented with a large stimulus object, right-handed participants responded slower with the right hand than with the left hand. Remarkably, our results indicate a compatibility effect as described by Wühr and Segeelke (2018) for left-handed participants (N=11) rather than for right-handed participants. The results of the present study generally do not contradict with ATOM in that for left- and right-handed people right-hand responses are faster to stimuli of larger size, but we put into question the extent of the compatibility effect regarding proposals of

previous studies, since our findings seem to be partly contradictory with previous findings.

*Keywords:* ATOM; compatibility; stimulus size; response location

Word count: 6198

Conceptual Replication of “Compatibility between Physical Stimulus Size and Left-right Responses: Small is Left and Large is Right”

ATOM (“A theory of magnitude”) is a theory proposed by Walsh (2003), which basically assumes a generalized magnitude-processing system in the brain where relations between the cortical representations of “time, space and quantity” exist. The theory predicts that if there were such relations, then there must be interference and congruency effects in experimental research investigating stimulus-response tendencies comprising different numerical, temporal or spatial properties.

Many studies have investigated different aspects and proposals of this theory in terms of stimulus-response (S-R) compatibility, where S-R compatibility refers to how “natural” it is for a certain required response (or action) to follow a given stimulus type. Typically, such compatibility effects are investigated by comparing reaction times for a required action or response in experimental tasks with a specifically defined stimulus-response (S-R) mapping that is varied within the experiment. In other words, the idea of a type of S-R compatibility-effect is thought to be supported if response times in an experiment are faster in the (pre-defined) “compatible” S-R mapping condition compared to an opposing “incompatible” S-R mapping condition. For example Dehaene, Dupoux, and Mehler (1990) found compatibility effects between numerical size and horizontal response location, which Dehaene, Bossini, and Giraux (1993) later coined as “Spatial-Numerical Association of Response Codes” (SNARC) effect. The SNARC effect is interpreted as an ordered spatial mapping of numbers to horizontal locations (left = small numbers, right = large numbers).

Furthermore, studies by Sellaro, Treccani, Job, and Cubelli (2015) and Ren, Nicholls, Ma, and Chen (2011) also gave rise to a SNARC-like compatibility effect for physical stimulus size and horizontal response locations, namely that responses with the left hand are faster when the target is a small-sized entity and responses with the right hand are faster for large-sized target entities. Wühr and Segeelke (2018) attempted and successfully

conducted a conceptual replication of the study by Ren et al. (2011).

In the experiment from Wühr and Segeelke (2018), participants were presented with “small” or “large” stimulus objects (simple black squares) and were required to judge their size as “small” or “large”. The keys for participants to communicate these judgments were mapped to either left- or right-hand responses and these mappings were switched once within the experiment. Wühr and Segeelke (2018) found, that participants were faster to respond to a large stimulus object with a key that is on the right of the keyboard (e.g. “backspace”, pressed with the right hand), than with a key that is on the left of the keyboard (e.g. “tabulator”, pressed with the left hand). For small stimulus objects, they found that reaction times were numerically faster for left-hand responses than for right-hand responses. Wühr and Segeelke (2018) claimed, that their results indicate the existence of a general magnitude code, as proposed in ATOM, and even more specifically, that people might intrinsically associate small objects with the left side and large objects with the right side.

For participants to judge whether the stimulus is a small or large object, ATOM would propose that subjects need to mentally activate an internal representation of size and the corresponding spatial response mapping in order to generate an action as response according to their judgment about stimulus size, and that these representations are linked. Ren et al. (2011), Sellaro et al. (2015) and Wühr and Segeelke (2018) showed that stimulus size and horizontal response location seem to indeed exhibit compatibility effects, which can be regarded as evidence for this sub-aspect of ATOM. They found that the horizontal response mapping (key press with either left or right hand) to judgments about stimuli of different size influences response behavior and matters for success and swiftness of judgments of “small” or “large” stimulus objects.

We here aim to assess the findings of Wühr and Segeelke (2018) via a conceptual replication of their first experiment. Because the compatibility effect was only shown for

right-handed participants in the original study, we sought to investigate, whether we can find this or another effect also in left-handed participants. Therefore, we extended the study by also recruiting and separately analyzing experimental data from left-handed participants.

In our study, analogously to the original experiment, a simple black square, which could be either large or small, was presented in each trial. Participants then had to decide with a keypress whether the displayed square was small or large. The reaction time was measured from stimulus onset until the keypress occurred. Our hypotheses were based on the results of Wühr and Segeelke (2018) that small stimuli are associated with left-hand responses, whereas large stimuli are associated with right-hand responses. We sought to replicate similar stimulus size - response location compatibility effects as those reported by Wühr and Segeelke (2018), i.e. we wanted to find out whether different stimulus-response mapping conditions have an effect on people's reaction times to stimulus objects of different physical size (specifically, large or small squares). Additionally, we aimed to investigate whether we can find compatibility effects in opposite direction for left-handed people, and to compare the size of the effect between left- and right-handed people.

In particular, we tested for right-handed people, if response times for right-hand responses are faster to the larger stimulus than to the smaller stimulus and similarly, if response times for left-hand responses are faster to the smaller stimulus than to the larger stimulus. Furthermore, we investigated whether the stimulus size – response location compatibility effect is larger for right-hand responses than for left-hand responses. This would mean, that the difference in response times for right-hand responses to be faster to the larger stimulus than to the smaller stimulus is larger than the difference in response times for left-hand responses to be faster to the smaller stimulus than to the larger stimulus.

Correspondingly, we tested the former hypotheses in opposite direction for

left-handed people. In other words, we assumed that the response times for left-hand responses are faster to the larger stimulus than to the smaller stimulus as well as that the response times for right-hand responses are faster to the smaller stimulus than to the larger stimulus. Analogously we hypothesized that here the stimulus size - response location compatibility effect will be larger for the left-hand responses instead of right-hand responses. Finally, we sought to compare the size of possible compatibility effects regarding people's handedness and assumed that the stimulus size - response location compatibility effect would be larger for right-handed people than for left-handed people, i.e. the absolute difference between response times in the compatible condition and response times in the incompatible condition would be larger for right-handed than for left-handed people.

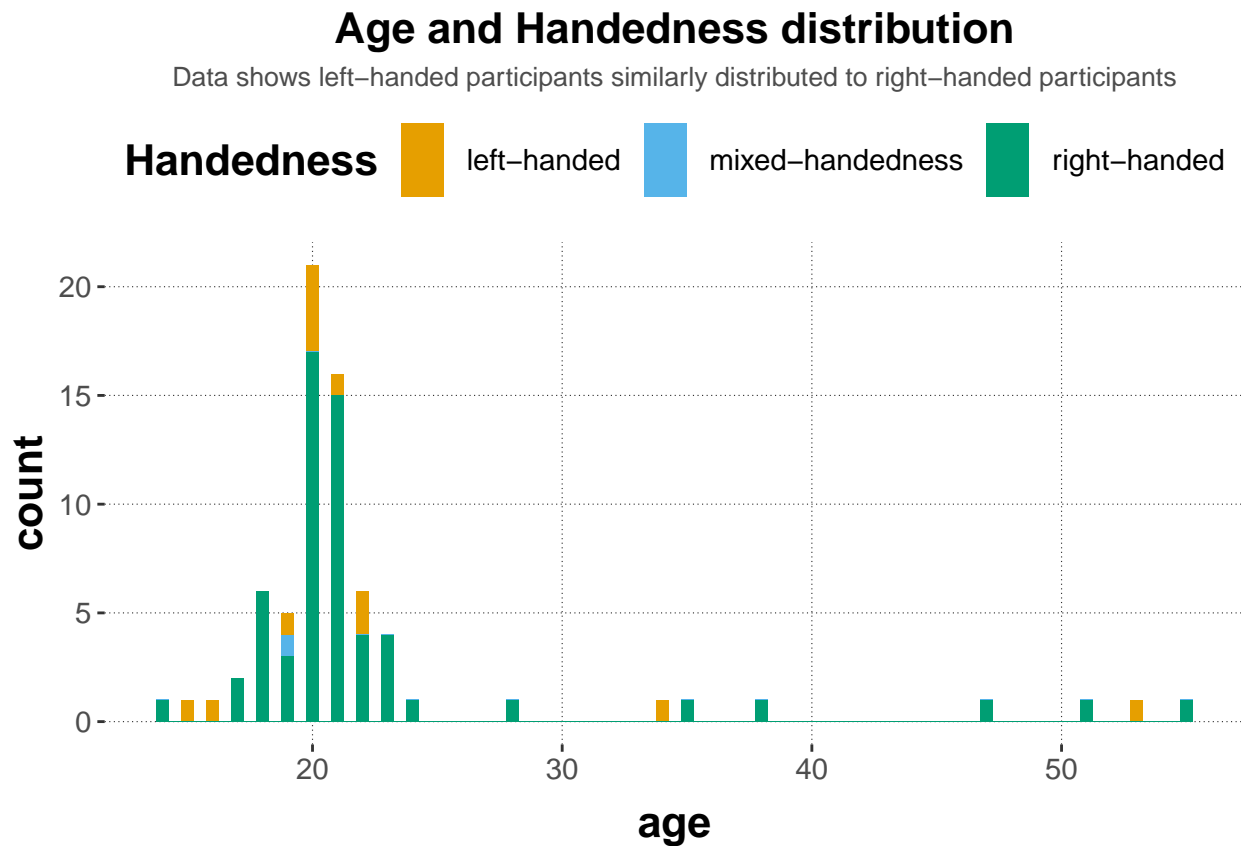
## Methods

We report demographics of our participants, all used materials, the experimental procedure, all data exclusions, and all performed data analyses.

### Participants

We recruited  $N = 72$  participants (43 woman, 27 men, 2 others, 22.60 = mean age, age range: 14-55 years) by distributing the link to the experiment via social media, mainly WhatsApp, Facebook and Reddit. The link was hosted on Netlify. 59 of the participants were right-handed and 12 were left-handed, as well as 1 participant indicating mixed-handedness (see Figure 1 for demographics). They were advised to take part only once, however, we did not control for this. On average, participants needed 12.89 minutes to complete the experiment, with a minimum time of 9.84 minutes and a maximum time of 21.07 minutes after filtering (explained in the data preparation section). The link was available for four days until we closed collection of data (from the 31st of July 2020 until the 3rd of August 2020). Before taking part, the participants declared to have normal or corrected-to-normal visual acuity and should be naive with respect to the purpose of the

study. Participation was voluntary and not rewarded with money or material things but with our deep gratitude.



*Figure 1*

## Material

In each trial, a visual stimulus object was presented in the center of the screen with white background. A stimulus object in the experimental block was a simple black square, which was either small (about 3 x 3 cm, depending on the size of the screen) or large (edges twice as long as those of the small stimulus, i.e. about 6 x 6 cm, depending on the size of the screen). We used information about the stimulus objects (i.e. information about how they are to be displayed concerning their form, size and position on the display) as provided by Wühr and Segeelke (2018), however we could not guarantee an exact same



formatting of stimuli for each participant in terms of equal edge lengths, but only in terms of relations between edge lengths, since the size of the displayed stimulus was relative to the screen on which it was presented. The two different types of stimulus objects (large and small square) were used for training trials and main trials in both experimental blocks. In addition to the original study, we included an intermediate block which was intended to distract participants from the previous, possibly internalised S-R mapping. A stimulus object in this block was either a simple black circle or a simple black triangle, both of small to intermediate size - regarding the small and large square stimulus objects' edge lengths - in terms of the circle's diameter or the triangle's height. All materials can be found in our GitHub repository under `experiment/01_materials`.

## Procedure

The experiment consisted of 10 parts. These parts comprised the two main experimental blocks, one for each of the two S-R mapping conditions, and one intermediate block with the distraction task. We varied the stimulus size - response (key) location mapping (S-R mapping) for the experimental blocks once over the course of the experiment. The order of S-R mapping conditions for the first and second experimental blocks (first = compatible – second = incompatible or first = incompatible – second = compatible) was determined experiment initially, uniformly at random once for each participant. In the compatible mapping condition, the small stimulus required a response with the left (“q”) key, whereas the large stimulus required a response with the right (“p”) key. The mapping was reversed in the incompatible mapping condition.

At the beginning of the experiment, participants were welcomed and given (not further specified) information about the general procedure, namely, that the experiment will consist of several parts, which again consist of several trials of tasks of similar structure. It was recommended to the participants to complete the whole experiment (to prevent dropouts from the beginning on), and they were given information about the

approximate duration of the experiment (about 15 minutes).

More precise descriptions of the participant's task were presented at the beginning of each block. These specific instructions included information about the sequence of events in a trial (fixation - stimulus presentation - key press or button click given the assigned S-R mapping), i.e. which keys to press for "small" or "large" stimuli (corresponding to the respective S-R mapping condition) in the experimental task blocks, or which buttons to click on for "circle" or "triangle" in the distracting task block, as well as information on whether the next part belongs to training (for the experimental blocks) or experimental phase (as in the intermediate block). Additionally, all instructions emphasized that participants should strive to optimize speed and accuracy (this was not mentioned in the original paper but seemed appropriate in this context, since a time-out occurred and an error message was displayed after the key press when participants' response time(RT) exceeded a period of 2000 ms).

After having read the experiment-initial information, participants were shown instructions for the first experimental block. After having read the instructions for this first experimental block, participants performed a training trial phase ( $2 \text{ stimuli} \times 5 \text{ repetitions} = 10 \text{ trials}$ ), before they could proceed to the main experimental trial phase for the respective S-R mapping condition ( $2 \text{ stimuli} \times 30 \text{ repetitions} = 60 \text{ trials}$ ). The first experimental block was followed by written instructions about the intermediate task, in which participants were shown either a circle or a triangle and had to classify the presented stimulus as "circle" or "triangle" by clicking on the respective button at the bottom of the screen. The intermediate task had ( $2 \text{ stimuli} \times 10 \text{ repetitions} =$ ) 20 main trials. The specific number of the intermediate task's trials was not necessarily optimal, but we decided on this as a -hopefully well- balanced compromise between effective distraction and no unnecessary prolonging of the experiment. The order in which participants were shown either of the two stimuli in the intermediate task was determined uniformly at random. After completion of the intermediate block's trials, participants were shown written

instructions of the following experimental block (similar to the initial experimental block's instructions, only different in the description of the S-R mapping, since it was reversed here). They then performed a training block ( $2 \text{ stimuli} \times 5 \text{ repetitions} = 10 \text{ trials}$ ) and an experimental block with the respective second S-R mapping ( $2 \text{ stimuli} \times 30 \text{ repetitions} = 60 \text{ trials}$ ). The order in which individual trials are presented in the training and experimental phases is determined uniformly at random and on the fly for each participant.

All experimental trials were structured as follows. Each trial started with the presentation of a fixation point (a small black “x” sign) for 1000 ms in the center of the screen. Afterwards, one of the two stimulus objects was displayed until a keypress (experimental blocks) or button click (intermediate block) occurred. In the experimental blocks, participants responded by pressing the left “q” key or the right “p” key on their keyboard. Participants should operate the left key (“q”) with the index finger of their left hand and the right key (“p”) with the index finger of their right hand. In the intermediate task, participants responded by clicking on the “circle” or “triangle” button at the bottom the screen. A correct response with a response time below 2000 ms after stimulus presentation was followed by a blank screen for 1500 ms. If the “q” or the “p” key was pressed after the maximum response period of 2000 ms, a corresponding error message (precisely: “Try to respond more quickly!”) was shown for 1500 ms in black color. In the intermediate block, however, each of the trials had to be initiated by clicking on a “start” button in the middle of the screen. In the main experimental blocks the next trial started automatically after the “p” or “q” key was pressed. Finally, the experiment terminated with a post-experiment survey asking participants for their preferred handedness (participants could choose between “right-handed” (default option), “left-handed” and “mixed-handedness”) and to optionally supply socio-demographic information (age, gender, native languages, whether there were any technical issues experienced during the experiment). Participants were able to leave comments on the experiment by entering them in a text field.

## Data Preparation

Firstly, we applied basic exclusions, namely only using experimental trials (not training or distractor trials) and only using trials where participants responded correctly to the stimulus by pressing the correct key. Secondly, we filtered out participants that responded faster than 100ms or slower than 1500ms. Thirdly, we log transformed the reaction times for use in our Bayesian regression models. The following part will describe two data exclusions which we did not state in our preregistration report that filtered out 3 and 1 participant, respectively. We aim to be transparent with the following two decisions and hope our rationale for them is understandable despite them being made after having seen the data.

Originally, our data contained 3 participants who needed drastically longer for the experiment than the average participant. We filtered out these 3 participants by choosing a threshold of 25 minutes, which these participants were well above. Figure 2 shows our rationale for choosing the threshold, as these three participants likely took a break during the experiment or performed another activity, which was not intended by our experimental design. This additional data exclusion criterion was not stated in our preregistration report, because we had not foreseen this unintended effect of conducting an online experiment, however the longer break in between trial blocks might cause those participants to perform differently in the following trials. To be on the safe side we therefore excluded these participant's data from our analyses.

Additionally, we filtered out one mixed-handed participant, since their data does not fit into our hypotheses, however we wanted to include the option in our post-experiment survey to not classify data incorrectly. We made this decision after submitting the preregistration report, but think this exclusion follows naturally from our hypotheses, since they only specify to use data from either left- or right-handed participants or both.

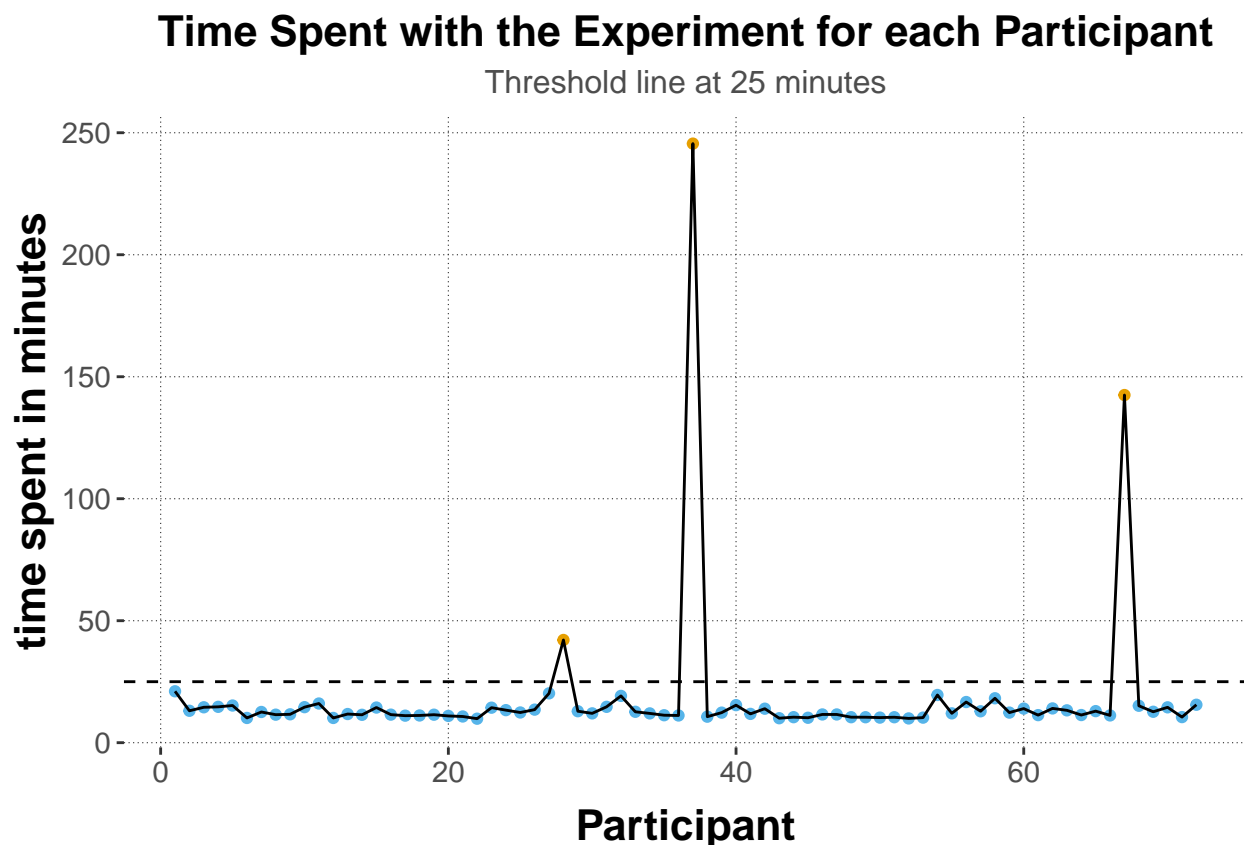


Figure 2

## Data analysis

We used R (Version 4.0.2; R Core Team, 2020) and the R-packages *aida* (Version 0.2.1; Franke, 2020), *brms* (Version 2.13.5; Bürkner, 2017, 2018), *broom* (Version 0.7.0; Robinson & Hayes, 2020), *dplyr* (Version 1.0.1; Wickham et al., 2020), *forcats* (Version 0.5.0; Wickham, 2020), *ggplot2* (Version 3.3.2; Wickham, 2016), *knitr* (Version 1.29; Xie, 2015), *papaja* (Version 0.1.0.9997; Aust & Barth, 2020), *purrr* (Version 0.3.4; Henry & Wickham, 2020), *Rcpp* (Version 1.0.5; Eddelbuettel & François, 2011; Eddelbuettel & Balamuta, 2017), *readr* (Version 1.3.1; Wickham, Hester, & François, 2018), *stringr* (Version 1.4.0; Wickham, 2019), *tibble* (Version 3.0.3; Müller & Wickham, 2020), *tidyr* (Version 1.1.1; Wickham & Henry, 2020), and *tidyverse* (Version 1.3.0; Wickham, Averick, et al., 2019) for all our analyses.

We analyzed our data with regard to the seven hypotheses we defined previously. To assess hypotheses 1-6 we defined two identical Bayesian regression models. They analyzed the influence of the factors S-R Mapping and Response separately on the (log-)Reaction Time as well as the interaction effect of S-R Mapping and Response on (log-)Reaction Time. We additionally accounted for group level variation between participants by adding random effects, namely random intercepts and slopes for the factor Response. We used the R package “brms”. Our first two models (model\_right and model\_left) were defined by the formula:

$$\text{logRT} \sim \text{Mapping} * \text{Response} + (\text{Response} \parallel \text{Participant})$$

For both models, the data is assumed to be Student-t-distributed and we did not replace the flat priors. Every other parameter of the models remained on the default setting. The models ran on the preprocessed data as described in section 22. data exclusion, however model\_right was only fitted with data from right-handed participants, while model\_left only used data from left-handed participants for fitting. The exact analysis can be found in our GitHub repository (a link is provided in the section “Data Accessibility Statement and Additional Files”). To assess hypothesis 7 we defined an additional model (model\_both) which only slightly differed from the two previous models and was defined by the formula:

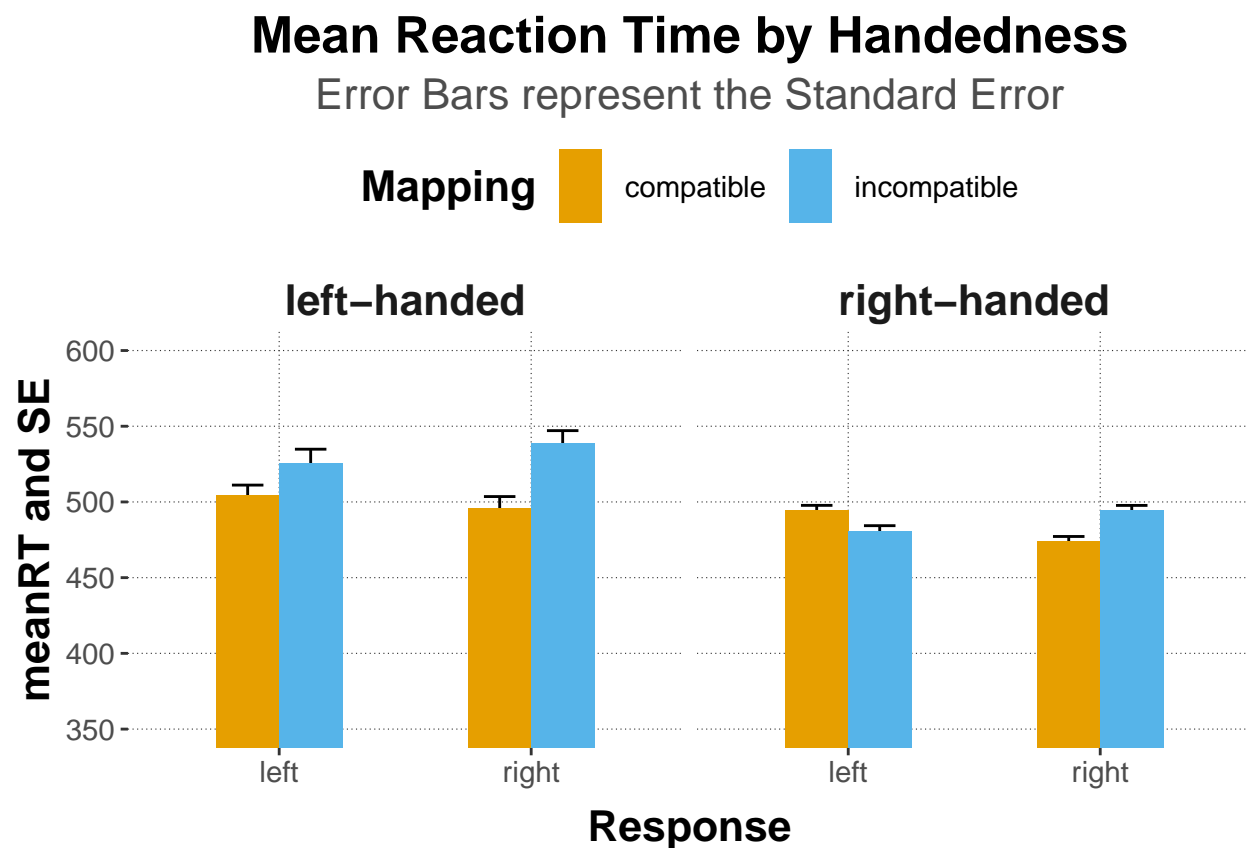
$$\text{logRT} \sim \text{Mapping} * \text{Handedness} + (1 \parallel \text{Participant})$$

The handedness of the participants replaced the response location as a factor influencing (log-)Reaction time. Random effects now only comprised a random intercept. This model used as dataset containing the exact same number of left- and right-handed participants. The family again was set to Student-t and the priors were left on the default setting (flat priors). The independent, manipulated variable was the S-R Mapping with levels compatible and incompatible, the further independent variable Response with levels left and right. These factors were encoded using the default dummy/treatment coding with

the group level combination “compatible” and “left” as the reference level. For Model 3, a further independent variable was the Handedness, dummy coded with reference level “right-handed”. The dependent variable was the (log-)Reaction Time.

## Results

In this section we present our statistical analyses. The following figure gives a rough overview of our data (Figure 3). Next, we will test our hypotheses.



*Figure 3*

When setting a random seed of 42 our analysis script yields the following results for our hypotheses (Table 1). Our hypotheses, as described before, are:

- (1) Response times for right-hand responses are faster to the larger stimulus than to the smaller stimulus.

- (2) Response times for left-hand responses are faster to the smaller stimulus than to the larger stimulus.
- (3) The stimulus size – response location compatibility effect is larger for right-hand responses than for left-hand responses. This means, the difference in response times for right-hand responses to be faster to the larger stimulus than to the smaller stimulus is larger than the difference in response times for left-hand responses to be faster to the smaller stimulus than to the larger stimulus.

Hypotheses (1)-(3) will be tested for right-handed participants only. Additionally, we will test the following hypotheses for left-handed participants, to investigate whether we can find a compatibility effect in opposite direction for left-handed people (opposing direction to Hypotheses (1)-(3)):

- (4) Response times for left-hand responses are faster to the larger stimulus than to the smaller stimulus.
- (5) Response times for right-hand responses are faster to the smaller stimulus than to the larger stimulus.
- (6) The stimulus size – response location compatibility effect is larger for left-hand responses than for right-hand responses. This means, the difference in response times for left-hand responses to be faster to the larger stimulus than to the smaller stimulus is larger than the difference in response times for right-hand responses to be faster to the smaller stimulus than to the larger stimulus.

Finally, we will compare the size of possible compatibility effects regarding people's handedness under the following hypothesis:

- (7) The stimulus size- response location compatibility effect is larger for right-handed than for left-handed people. I.e., the absolute difference between response times in



Table 1

Hypothesis	Bayes_factor	Post_prob
1	$\infty$	1.0000
2	0.0000	0.0000
2_inv	$\infty$	1.0000
3	$\infty$	1.0000
4	0.1393	0.1223
4_inv	7.1800	0.8778
5	0.0000	0.0000
5_inv	$\infty$	1.0000
6	1,332.3333	0.9992
6_inv	0.0008	0.0008
7	0.0104	0.0102
7_inv	96.5610	0.9898

the compatible condition and response times in the incompatible condition is larger for right-handed than for left-handed people.

A Bayes factor above our predefined threshold of 25 is interpreted as a sufficiently large support in favor of our hypotheses. A Bayes factor below 1 should be interpreted as negative support or support for the inverse hypothesis. The inverse hypothesis here is defined by simply switching “>” to “<” or vice versa in the equation for the hypothesis testing. The posterior probability of the inverse hypothesis is simply defined by (1 - the probability of the original hypothesis). To also quantify the Bayes factor and therefore the support for the inverse hypothesis, we will also explicitly test for the inverse hypothesis.

According to these rules we can conclude the following for our hypotheses:

Hypothesis 1 receives enough support to be accepted.

Hypothesis 2 receives no support at all. The inverse of hypothesis 2 receives enough support to be accepted. We therefore conclude that right-handed participants left-hand responses' are faster to the larger stimulus than to the smaller stimulus.

Hypothesis 3 receives enough support to be accepted. However since we did not find the assumed effect for left-handed responses (H2), the result of H3 is not very useful either.

Hypothesis 4 receives not enough support to be accepted. There is stronger evidence for the inverse of hypothesis 4, however this support is not above our threshold. This means we can only report a tendency to the inverse of hypothesis 4, namely that left-handed participants response times' for left-hand responses are faster to the smaller stimulus than to the larger stimulus.

Hypothesis 5 receives no support at all. The inverse of hypothesis 5 receives enough support to be accepted. We therefore conclude that left-handed participants response times' for right-hand responses are faster to the larger stimulus than to the smaller stimulus.

Hypothesis 6 receives enough support to be accepted. However since we did not find the assumed effect in left-handed participants (H4,H5) and since we have rather strong evidence for the inverse effect, we should rather inspect the inverse of hypothesis 6. The inverse of hypothesis 6 receives not enough support to be accepted. Therefore we should conclude that the stimulus size – response location compatibility effect in left-handed participants is larger for right-hand responses than for left-hand responses.

Hypothesis 7 receives not enough support to be accepted. The inverse of hypothesis 7 receives enough support to be accepted, therefore we should conclude that the stimulus size- response location compatibility effect is larger for left-handed compared to right-handed people.

## Discussion

The results of the present study are in line with the hypothesis that for right-handed people, right hand responses are faster to larger stimulus objects than small ones. However (first surprise), we did not find evidence for a similar stimulus-size dependent facilitation effect for small objects and left-hand responses. Contrarily, we rather found an effect in the opposite direction of our second hypothesis, namely that left-hand responses were faster to larger stimuli as well. Thus, our third hypothesis, namely that the effect for right-hand responses to be faster to the larger stimulus than left hand responses to be faster to the smaller stimulus is not applicable anymore. Surprisingly (second surprise), we found that for left-handed people, the results of this study do not provide evidence for a stimulus-response compatibility effect in the proposed direction, but show a rather strong effect in opposite direction, i.e. in the same direction as suggested for right-handed people. In our study, left-handed people were faster when responding to a large stimulus with the right hand than to a small stimulus. Furthermore, we could even find a tendency of left-hand responses in left-handed people to be faster to the smaller stimulus than to the larger stimulus. These results let us reject our hypotheses concerning the effect and its direction for left-handed people but would match well with our first three hypotheses which we originally proposed in order to investigate the effect for right-handed people. Moreover (third surprise), opposing to our last hypothesis about the size of the effect being larger for right- than for left-handed people, we found that the common aspect of the effect between the two groups, namely that responses are faster in the compatible mapping condition, was apparently larger for left-handed people than for right-handed people.

## Comparison to previous studies

This pattern of results is partly consistent with the original experiment's results from Wühr and Segeelke (2018) which we aimed to replicate in the present study. Specifically,

we successfully replicated their finding that right-hand responses were faster to the larger stimulus than to the smaller stimulus for right-handed people. Interestingly, in the present study, results indicate that for left-handed people, the effect was even more consistent with the results of their study. Nevertheless, whereas Wühr and Segeelke (2018) and similarly Sellaro et al. (2015) in their first experiments, respectively, have found, that left-hand responses were faster to smaller visual stimulus objects than to larger visual stimulus objects, we could rather detect a tendency in the opposite direction in the present study, namely left-hand responses being faster to larger stimulus objects as well. In accordance with the findings of Ren et al. (2011), Sellaro et al. (2015) and Wühr and Segeelke (2018), we also found that the stimulus size – response location compatibility effect was larger for right-hand responses than for left-hand responses in right- and left-handed people (when disregarding the reversed direction of the effect for left-hand responses in right-handed people). Thus, the results of the present study represent a first demonstration of a facilitatory effect of large stimuli (in physical size) for left-hand as well as right-hand responses in right handed-people, contrary to the facilitatory effect of small stimuli for left-hand responses which past researchers have found (Ren et al., 2011; Sellaro et al., 2015; Wühr & Segeelke, 2018). Interestingly, we could find supporting evidence for their claims that there might be an implicit association of physical size and horizontal positions in the form of shared mental representations of different physical size and left-right polarities in extension of the SNARC effect, but only for left-handed people.

### **Theoretical implications**

Our findings highlight that stimulus size indeed relates to different response latencies depending on the horizontal (i.e. left or right) response location in the sense of a stimulus-response compatibility effect, but only for large stimulus objects and right(-hand) responses. Interestingly, results for left-handed participants in the present study were even more consistent with the proposals for a SNARC-like effect than for right-handed people,

which were demonstrated by previous research (Ren et al., 2011; Sellaro et al., 2015; Wühr & Segeelke, 2018). However, it is interesting that we did not detect a such specific stimulus size-response location compatibility effect for left and right responses in right-handed people as the given previous researchers. Since we found that responses for either (left or right) hand are facilitated by larger stimulus objects for right-handed participants, we would rather suggest that there is an effect of physical stimulus size on response latencies irrespective of the horizontal response location, although we indeed found supporting evidence for a SNARC-like size and space dependent compatibility effect in left-handed participants, i.e. left-hand responses tending to be faster to small stimuli and right hand responses to large stimuli. We will disregard the results of the present study for left-handed people and left hand responses to be faster to the smaller stimulus, because a larger sample size than in the present study ( $N = 11$ ) would be required to detect effects with more confidence, and because left hand-responses were not significantly faster to small stimuli than to large stimuli (regarding our predefined threshold). This finding of a size-dependent response facilitation effect may be explained by the idea that large stimuli are naturally perceptually more salient than small stimuli and can thus be recognized as such faster than small stimuli, which might facilitate cognitive processes for task-dependent response generation (i.e. enabling faster action preparation and execution in response to the presented stimulus). Taken together, our findings indicate that there is no sure differential effect of physical stimulus size (small or large stimulus objects) and horizontal response location (left or right key press) in left- and right-handed people as proposed by Wühr and Segeelke (2018) (among others), but rather an effect of physical stimulus size on response time.

### **Limitations of the present study**

Besides our limited sample size of left-handed participants, there are some other aspects in the design of our study, that might have influenced our results and might

account for the previously discussed inconsistencies with findings of research by Wühr and Segeelke (2018). Firstly, we effectively had a much larger sample size ( $N = 57$ ) than Wühr and Segeelke (2018) ( $N = 24$ ), meaning that we had more than double the amount of data for right-handed participants than they had in their original study. This difference might also account for the different manifestation of the effect we observed in left-handed participants. Thus, we suggest that left-hand responses might generally not be faster to small stimuli than to large stimuli (if the sample size is large enough), since we did not find compelling evidence from our larger sample of right-handed participants, and observed no significant effect but only a tendency for left-handed participants. However, results from our study might be biased for other reasons as well. Firstly, we probably did not collect a random sample of participants as a good representation of the whole population of left- or right-handed people (irrespective of our sample size), since participants were mostly recruited via social media or messenger apps. Thereby, we were able to recruit only a very small subpopulation of people with possibly similar sets of characteristics (e.g. capability of understanding the experiment's instructions (given in English), access to the required technical necessities (PC/laptop/device with manual keyboard and stable internet connection), willingness to take part in our experiment and thereby support us in our studies, ...). Secondly, since we conducted our study as a browser-based experiment, technical differences and differences in the hardware used to execute the experiment between participants, as well as our inability to control for correct understanding or execution of the experiment's instructions might have influenced the results. Thirdly, we addressed the issue of unequal number of training trials before the first and second S-R mapping condition in the original experiment by Wühr and Segeelke (2018) by including an intermediate distracting task in our experiment and consequently halving the number of training trials for the second experimental block, such that there were equally many training trials for both S-R mapping conditions. Yet, we cannot imagine how this deviation from the original experiment might have had critical influence on the S-R compatibility

effect we aimed to replicate, given that the order of S-R mapping conditions was assigned randomly for each participant. Although we cannot rule out any possible effects of these potential confounders, it seems necessary to point out issues that may conflict with the present study's results.

### **Outlook for future research directions**

Because our study just partly supports previous findings, it's most important contribution may be that it raises a variety of intriguing questions for future research. One suggestion to find evidence in favor of or against a compatibility effect as proposed by Wühr and Segeelke (2018) would be to restructure the design of the experiment in such a way, that it becomes a discrimination task which only requires responses in the form of a key press at a specific horizontal position, if a stimulus of specific size is present. Participants would indicate via a one-sided response with one hand at a time only if either a small or large stimulus is shown, meaning less cognitive demands for the participants and thereby limiting possible confusion of stimulus judgement outcomes and pressing of the intended corresponding key. I.e., participants would have to press a key with either the left or right hand if the required stimulus is present and not to press this key if the required stimulus is absent or the other stimulus is shown. We find this design idea especially interesting, since it would not require substantially different means of analysis as those we used in our experiment. It could also possibly require fewer training trials than used in the present study, because for this simplified version of the task, less practice might be needed. Another interesting suggestion for a different execution of the current study would be what has already been suggested by Wühr and Segeelke (2018). One could include a crossed-hands condition to investigate whether the effect is related to the (hemispheric) response side itself or the handedness of a person, although our results do not indicate a substantial modulation of the effect by people's handedness. In addition to those already mentioned possible directions of future research, we suggest to conduct a study similar to

the present study with more left-handed participants (and similar amount of right-handed participants) than we had, because the compatibility effect we found could be due to insufficient sample size, and we hypothesize that it might also be the underlying cause for our results to deviate from the findings by Wühr and Segeelke (2018), which might be due to the small amount of participants they recruited. It could be possible that even the tendencies for the compatibility effects we observed for left-handed participants might actually not be generalizable as well. In terms of future research, it would also be interesting to find out if there is a compatibility effect in children, who did not start to learn reading and writing yet, because children's reactions at this age might be not or only very little biased towards the anatomical status of their hands, which would rule out this factor as a possible modulator of the S-R compatibility effect in question.

### Conclusion

Although the generality of the current results must be established by future research, the present study has provided clear support for right hand reactions to be faster to larger stimulus objects than to smaller stimulus objects. Not only was this observed for right-handed, but also - and possibly even more strongly - for left-handed people. Having said that, we found no clear and (for left- and right-handed people) consistent evidence for the claim, that there is a mapping of small and large objects to distinct horizontal positions. Given our observation that for experimental trials in which large stimuli were presented, participants exhibited faster mean reaction times, we rather suggest a facilitatory effect of the presentation of large objects on cognitive processing, depicted by faster responses with either hand. What is important to note, is that this mostly holds for right handed-participants in our study, whereas tendencies in the results from left-handed participants rather seem to support the idea of a cognitive spatial (horizontal) mapping of size as proposed by previous researchers (Ren et al., 2011; Sellaro et al., 2015; Wühr & Segeelke, 2018). Though, these are only tendencies. Further research in this field would be



required in order to better estimate the specification of a stimulus-size dependent response-position compatibility effect, which we failed to replicate. We hope that the current research will stimulate further investigation of this area.

### **Data Accessibility Statement and Additional Files**

The raw and preprocessed data from our experiment and our analysis files, as well as a precise description of the experimental design, including a discussion of possible design alternatives, files with all materials used in the experiment, and the code for the implementation of our experiment using `_magpie`, a minimal architecture for browser-based experiments using JavaScript, can be accessed via the following link to our github repository for this study:

Experimental Files

Additional Plots

The following plots give further insight into our data and display interesting aspects of it, but are not included in our discussed results. Figure 4 (left-handed data) and 5 (right-handed data) use Local Polynomial Regression Fitting (loess) to fit curves to the reaction time data. Here, we distinguish between the S-R-Mappings and whether participants responded with their left or right hand. Additionally, Table 2 shows that our first-mapping randomization resulted in an even distribution of mappings in every block.

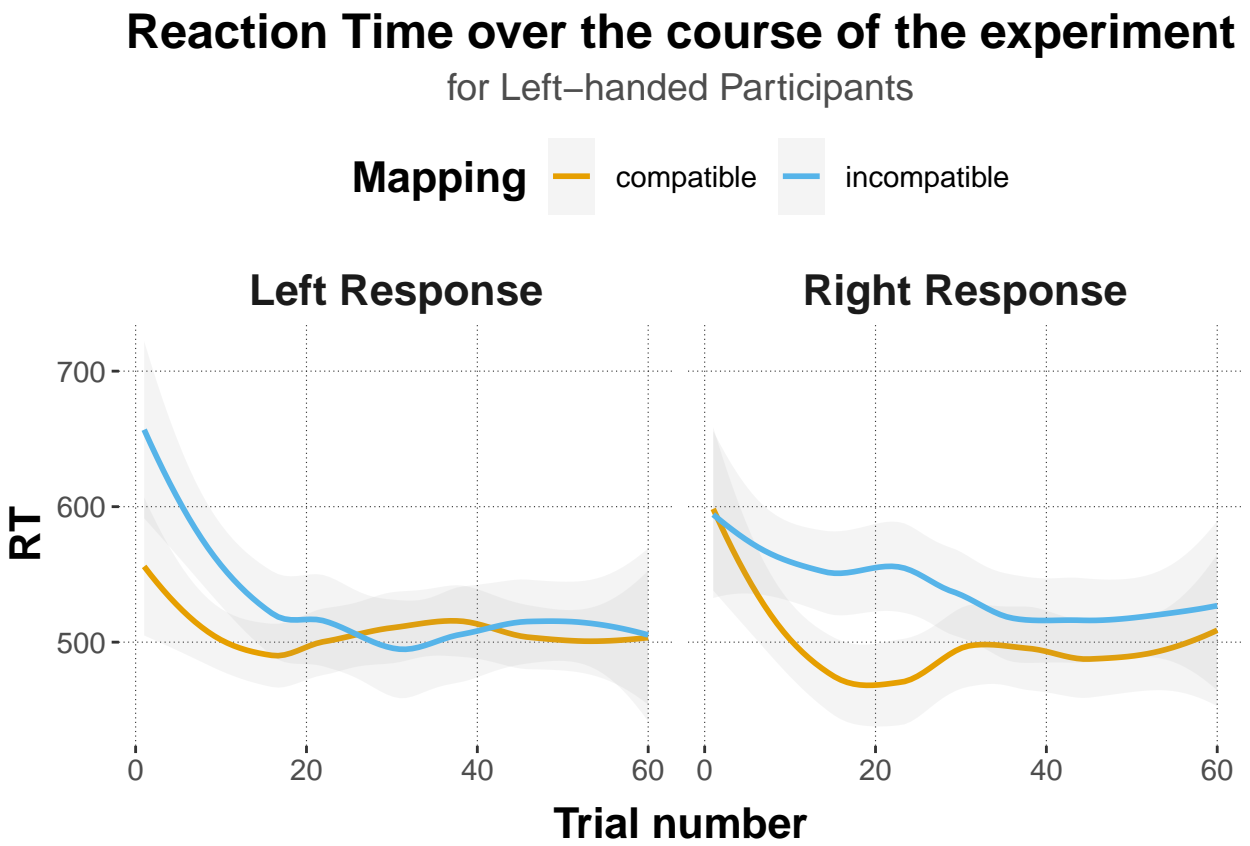


Figure 4

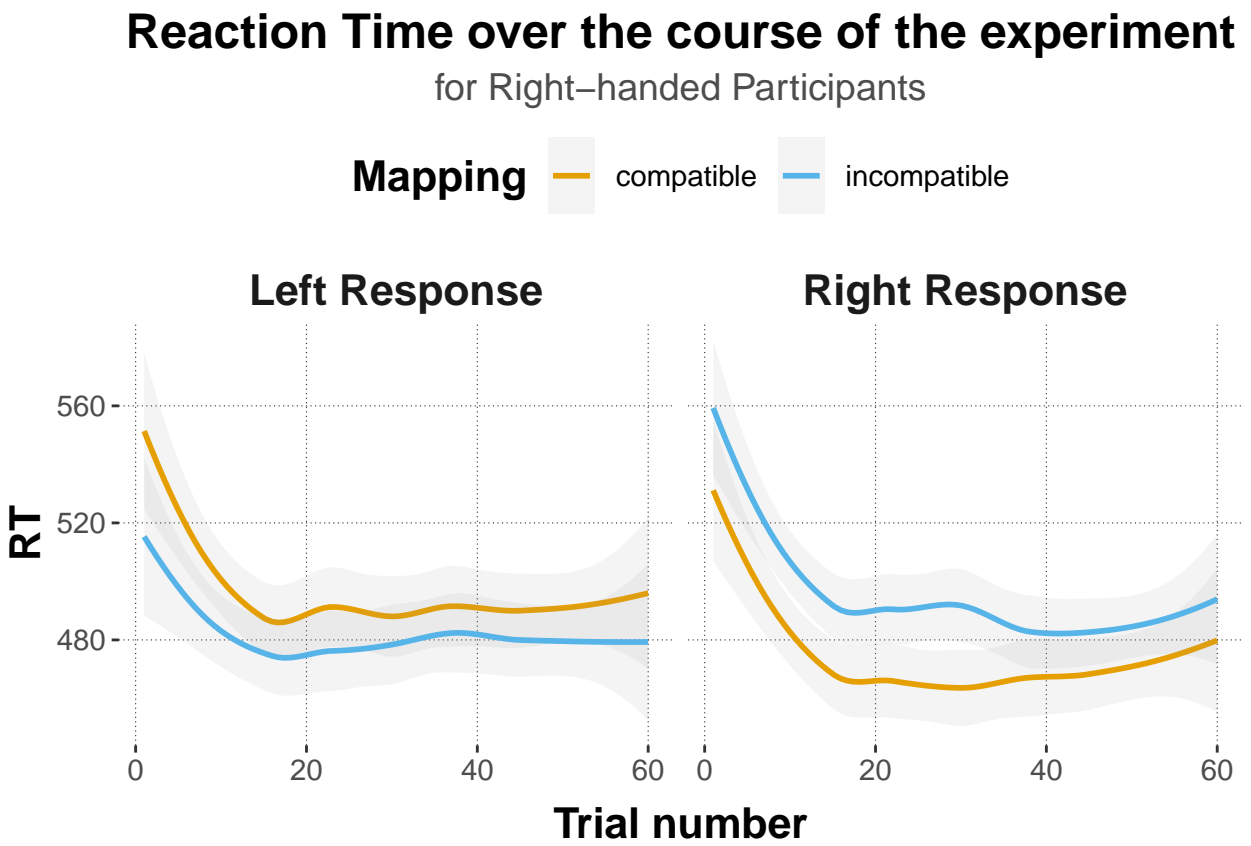


Figure 5

Table 2  
*Number of participants that were assigned a certain mapping as their first block.*

Handedness	Mapping	n
left-handed	compatible	6
left-handed	incompatible	5
right-handed	compatible	29
right-handed	incompatible	28

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