

# Spatial Reasoning in Native Speakers of Russian and German

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## Abstract

The relationship between reasoning and language has been frequently studied. Here we explore principles of spatial reasoning in Germans and Russians. We compared the performance of Russians in three different settings to the performance of Germans. The task was to construct layouts of wooden blocks according to verbal instructions, describing the relations of these blocks. Subsequently pieces of new information, introduced as incontrovertible facts and partly contradicting the initial descriptions, were given. Participants re-arranged the blocks to take into account the new facts. Recent research conducted with Germans has shown that – although alternatives are logical equivalent – there are preferences for certain solutions. The question was whether Russians show the same or different preferences. Our results suggest that construction and revision of spatial models follow similar principles. However, we observed differences between the groups regarding the flexibility to apply a principle based on the order of words in a sentence.

**Keywords:** Spatial reasoning; Relational reasoning, Cross-cultural similarities; Language; Russia; Belief revision

## Introduction

Misunderstandings happen so often between people from different countries, triggering the important question: how is language connected to our mental representation of the world? What role does it play in reasoning? Answers suggested to that question are provided by an important theory in that area: the Sapir-Whorf hypothesis affirms that language influences thought (Zvegintsev, 1960; Levinson, Kita, Haun, & Rasch, 2002; Levinson & Meira, 2003). On the other hand, there is the view that the mind is organized in a modular way with separate modules dedicated to certain abilities (e.g. Tsimmerling, 2000; Nowak, Komarova, & Niyogi, 2001; Kulikov, 2012). A further important question, to some extent related to language, is: how do mental representations differ across different cultures? What role do cultural backgrounds play in reasoning? While some studies suggest cultural dissimilarities (e.g. Oyserman & Lee,

2008), other studies show that there are common cognitive principles used by reasoners of different cultures. Cross-cultural similarities have, for instance, been shown in topological reasoning (Knauff & Ragni, 2011; Knauff, 2013).

The present study is concerned with spatial relational reasoning and the influence of language and culture. We briefly analyze relevant work on linguistic influence on thinking, comparative topology of German and Russian, and spatial relational reasoning. We then present an experiment, designed to investigate the construction and revision of spatial models.

## Construction and Revision of Spatial Mental Models

Imagine you need to find the house № 28 in a street, unfamiliar to you. You have received the following description of the precise location by friend A, informing you that:

- (1) “There is a hotel to the right of a café.”, and
- (2) “The house № 28 is to the left of the café.”

The description allows for one (determinate) model to construct. In order to construct the model, spatial information is inserted successively. Based on the information given by statement (1), the model

- (3) “Café – Hotel”

is initiated and extended by (2) “House № 28”, resulting into the model:

- (4) House № 28 – Café – Hotel

A lot of studies have explored factors that influence reasoners when they construct models, among them the order of objects as inserted into the model, and other order effects (e.g. Payne, 1993; Ehrlich & Johnson-Laird, 1982; Payne & Baguley, 2006; Bucher, Krumnack, Nejasmic, & Knauff, 2011; Krumnack, Bucher, Nejasmic, & Knauff, 2011; Nejasmic, Krumnack, Bucher, & Knauff, 2011).

Imagine you find out a little later that the information uttered by friend A is unreliable. Friend B – who lives in the street in question – informs you that as a fact:

(5) “The house № 28 is to the right of the hotel.”

The more reliable and incontrovertible information partially contradicts friend A’s description needs to be taken into account. The following alternatives are possible:

(6) Café - Hotel - House № 28

(7) Hotel – House № 28 – Café

Both variations of the initial model are logically equivalent. Nevertheless, when confronted with ambiguous relational information, human reasoners frequently prefer one alternative over the other (Jahn, Knauff, & Johnson-Laird, 2007; Krumnack, Bucher, Nejasmic, & Knauff, 2010; Bucher et al., 2011; Krumnack, Bucher, Nejasmic, Nebel, & Knauff, 2011; Bucher & Nejasmic, 2012; Knauff, Bucher, Krumnack, & Nejasmic, 2013).

### Preferred model revision

The process of model revision with verbal descriptions, using binary relations  $r(X,Y)$  as facts has been shown to rely on the following principle: the functional distinction of X as the “to-be- located object” (LO) in contrast to Y as the “reference object” (RO) specifies the location of the LO relative to the known location of the RO (e.g. Huttenlocher & Strauss, 1968; Miller & Johnson-Laird, 1976; Talmy, 1983; Landau & Jackendoff, 1993). For the revision of horizontal linear arrangements, the following finding concerning reasoners’ preferences is characteristic

Initial arrangement      A B C  
Counterfact                C is left of A,  
with C as the relation’s LO  
Preferred revision:        C A B

Note that the logical equivalent (non-preferred) alternative for revising the initial model by relocating the counterfact’s RO (here: A) would results in the revised model: B C A. We refer to the preferred principle as the LO-principle (compared to the RO-principle).

### Linguistic Influence on Thought and Comparative Typology of German and Russian Languages

The Sapir–Whorf hypothesis postulates that language determines thought or at least that linguistic categories influence thought and certain kinds of non-linguistic behavior (Zvegintsev, 1960). Li and Gleitman (2002) investigated influences of individual languages (e.g. English and Dutch) on spatial reasoning. Chatterjee (2011) studied language as a form of mental representation of space. With the current study, we investigate influences of different languages (Russian vs. German) on spatial mental representations. Moreover, to dissociate between influences that result from linguistic aspects on the one and cultural aspects on the other hand, the study took place in two cultural settings (in Germany and in Russia).

First, we briefly explain the structures of both languages in terms of comparative typology. Both languages are from the Indo–European family. German belongs to the West Germanic family, Russian is a Slavic language. They are inflexional languages (from Lat. Flectivus «flexible»). The term refers to a language, where word-building with inflexions dominates. Inflexions are morphemes which can have much significance; e.g. the article „die“ (as in “die Katze”, “the cat”) in German, indicates the gender (feminine), the case (nominative), and the number (singular). Russian is even more inflexional compared to German. Inflexional languages can be synthetic or analytic. The German language is between the synthetic and analytic languages, it has some characteristics of both language types. In a synthetic language, a word contains all the grammar, e.g., by inflexional endings, prefixes, suffixes. An analytic language is a language which reproduces grammatical relationships syntactically. Accordingly, it uses only unbound morphemes, and only separate words like articles etc. (Anokhina & Kostrova, 2006). For instance: “хорошая новость” and “eine gute Neuigkeit” (“good news”) – in Russian, the ending „ая“, and in German the (additionally needed) article „eine“ indicates: feminine, nominative, singular. There are some more differences between German and Russian which we do not want to explain here in detail. What is relevant for the current study is the flexibility in word order in the two languages. In German, the possibility of ordering words within a sentence in a certain way is much more limited compared to Russian. Of course, the “freedom” of word order in Russian is not unlimited and also regulated by semantic and stylistic factors (as in German) (Anokhina & Kostrova, 2006). An example is given in table 1.

Table 1. Word order in German and Russians languages

Russian	German	Exact meaning
Я люблю тебя	Ich liebe Dich	I love you
Тебя я люблю	<i>Word order not possible</i>	I love you, exactly you, not another person
Я тебя люблю	<i>Word order not possible</i>	I love you, exactly you, not another person
Люблю я тебя	<i>Word order not possible*</i>	I love you (with an even stronger significance in the sense that I can do nothing about it)
Люблю тебя я	<i>Word order not possible**</i>	You are loved by me, not someone else
Тебя люблю я	Dich liebe ich	I love you, exactly you, not another person

\*the word order would be possible in a German question (“Liebe ich Dich?”); \*\*the word order would be possible in a German passive sentence (“Du wirst von mir geliebt.”)

Analogously, the Russian spatial language is also more flexible than the German language. For example, dynamic local relations in German indicate source locations (“where from?”) and directions of motion (“where to?”), while in Russian such relations have a triple function, they indicate: location (“where”), source location, and direction (Khoruzhaya, 2007).

To summarize, there are major differences between German and Russian. Previous research on spatial relational reasoning suggests that reasoners have strong preferences which are often based on linguistic cues that are connected to the sentence structure. The main finding in a range of experiments on the variation of spatial models (Bucher et al., 2011; Krumnack et al., 2011; Bucher & Nejasmic, 2012; Knauff, et al., 2013) is that the variation is preferably done by the relocation of objects that are perceived as more flexible compared to other objects. These objects are usually the so called to-be-located objects (LO) of a relational statement as compared to reference objects (RO) which are perceived as more stationary. We refer to this preference as the LO-principle.

The question is whether cognitive principles such as the LO-principle are used independently from linguistic or cultural aspects. Concerning the language aspect, it would be plausible if Russians, i.e. native speakers of a language that is by nature very flexible concerning the word order and sentence structure are accordingly more flexible in the application of such cognitive principles. In this specific case they might use the RO-principle more frequently as an alternative solution in the reasoning task. Culture is another important aspect to look at when we look at similarities of cognitive principles. There are many definitions of culture. Oyserman and Lee (2008, p. 311) say that “culture matters to the extent that individuals living in different societies are likely to have differing experiences”. Criado (2009, p. 295) explains that culture is “a set of shared values, beliefs, expectations, customs, jargon, and rituals”. What seems to be indisputable is that a cultural environment can have an impact on the way an individual thinks.

In order to explore both, language and culture influence, we conducted the same experiment with native speakers of German and of Russian as participants. Three different samples of Russian participants were tested in two different cultural environments:

1. The first sample was tested in German, in Germany
  2. The second sample was tested in Russian in Germany
  3. The third sample was tested in Russian in Russia
- The purpose was to control for both, the language and the cultural setting.

## Experiment: Construction and Revision of Block Arrangements

### Method

The first part of the experiment can be referred to as “construction phase”. The task was to physically construct layouts of wooden blocks according to a verbal instruction,

describing the relations of these blocks. The second part can be titled “revision phase”. Once a layout was constructed, a piece of new information, introduced as an incontrovertible fact contradicted a part of the initial description. The task was to re-arrange the blocks such that it cohered with the “fact”.

**Participants** Altogether, we tested 76 volunteers who performed in the task either in German or in Russian in Germany or in Russia. All participants gave informed consent to participation. Participants were tested individually. Each participant was tested only once.

Language abilities were assessed by self-report. Russian participants tested in Germany rated their German language abilities as “very good”, and reported to be capable of writing and speaking fluently. They were fluent in Russian as their mother tongue and in German as a second language, and have been living and were educated in Germany for a considerable time. Russian participants tested in Russia reported to be not familiar with the German language while German participants reported to be not familiar with the Russian language.

**The sample of Germans tested in German in Germany** consisted of 11 (5 male; age:  $M = 24.91$ ;  $SD = 2.95$ ) native speakers of German, all students from the University of Giessen. None of them has ever studied Russian.

**The sample of Russians tested in German in Germany** consisted of 19 (3 male; age:  $M = 24.05$ ;  $SD = 4.18$ ) native speakers of Russian.

**The sample of Russians tested in Russian in Germany** consisted of 20 (3 male; age:  $M = 25.45$ ;  $SD = 5.26$ ) native speakers of Russian.

**The sample of Russians tested in Russian in Russia** consisted of 26 (1 male; age:  $M = 20.35$ ;  $SD = 0.63$ ) native speakers of Russian. They were all students from the Federal University of Kazan (among them 19 students of psychology). None of them has ever studied German or has been to Germany.

**Materials, Procedure, and Design** 32 items were presented, each consisting of two premises and an inconsistent fact. The task was presented on a 19“-computer screen, using Microsoft PowerPoint (Version 2007) running in the windows environment XP on a standard personal computer. PowerPoint slides were presented by the experimenter in a sequentially and individually adapted manner according to participants’ performance.

In all items, the two premises and the contradictory fact (presented in red) had the surface structure as follows: first object - relation (either “left of” or “right of”) – second object.

Example: “Yellow left of red”

Participants were provided with wooden square blocks (size: 2.5 x 2.5 x 2.5 cm), red, green, yellow, and blue colored on a plate in front of them and instructed to construct and subsequently revise their block layouts.

*The construction phase:* participants were instructed to pick up the colored blocks, one at a time using one hand, and arrange them according to the information provided by

the premises into a linear one-dimensional order. The premises informed about the determinate order of the blocks with the blocks represented by the respective colors (red, green, yellow, and blue).

Example:

1st premise: “Blue right of red”

2nd premise: “Green right of blue”

Spatial arrangement: red – blue – green

The location of the third object was counter-balanced across all problems. In a recent experiment, very similar to the one reported here, and presented in German to German participants, word order has been shown to be crucial for the physical construction of spatial models (Bucher et al., 2011, Experiment 2). Here, accordingly, based on the description of the 1<sup>st</sup> premise, two possible construction orders were possible:

1. Starting on the left side and continue to the right, e.g. (consider the 1st premise from the above example) putting down the red block first and placing the blue block to the red one’s right side.
2. Starting on the right side and continue to the left, e.g. putting down the blue block first and placing the red block to the blue one’s left side

The resulting orders are describable as 1 – 2 – 3 and 2 – 1 – 3, with the numbers indicating the order by which objects had been put down; e.g. red first – blue second – green third (order 1 – 2 – 3) and red second – blue first – green third (order 2 – 1 – 3). The question was whether there would be order effects when constructing the arrangements in the Russian samples similar to those found in Germans.

*The revision phase:* subsequently after participants had constructed the order of the three colored blocks, they were asked to revise their order according to the inconsistent fact.

Example-fact: “Green left of red”

Participants were free with the revision of their initially constructed arrangements. After each trial, the wooden blocks were put back onto the plate by the experimenter. Four practice trials (neither recorded nor analyzed) preceded the experimental trials. Performance was recorded on a video tape by the experimenter and analyzed after the experimental session (Bucher et al., 2011).

In previous experiments, using a very similar experimental set-up, presented in German to German participants, the finding was that of a clear preference (e.g. 89.52 %,  $SD = 11.30$ ; see Bucher et al., 2011, experiment 2) of LO relocations as compared to RO relocations. The question was whether participants of the Russian samples would apply the LO-principle similarly to the German participants.

## Results and discussion

*Construction:* Mean percentage rate of correctly constructed orders was 97% ( $SD=4.46$ ). There was no difference in number of mistakes in construction between the samples ( $p > 0.30$ ). We analyzed the order of objects put down during the construction in every sample, running Wilcoxon’s tests for each sample, separately (Siegal & Castellan, 1988). In the German sample the 1-2-3-order was

used more frequently compared to the 2-1-3-order ( $z = -2.01$ ;  $p < 0.05$ ). The same applies to the remaining samples: Russians tested in German in Germany ( $z = -3.93$ ;  $p < 0.01$ ), Russians tested in Russian in Germany ( $z = -3.97$ ;  $p < 0.01$ ), and Russians tested in Russian in Russia ( $z = -4.49$ ;  $p < 0.01$ ). Our results provide evidence that the same principle (putting down blocks in word order 1-2-3 rather than in the order 2-1-3) was applied similarly by participants of all four samples. Thus, we can conclude that the cognitive principle is not affected by linguistic aspects. Russians tested in Germany as well as Russians tested in Russia used the same principle, suggesting cross-cultural similarities.

We continued our analysis by comparing the magnitude of the preference applied by Germans and Russians in the different settings. The Kruskal-Wallis test revealed a difference between the samples ( $p < 0.05$ ). Pair wise comparisons, using Wilcoxon’s tests revealed that the group of Germans differed from all Russian samples (all  $ps > .05$ ).

Despite the overall similarities found across all samples, we found that Russians were more strictly in the application of this principle. The Germans performed more flexible in the task, using the alternative word order (2-1-3) more frequently. Figure 1 depicts the result graphically. We continue to discuss this difference in the General Discussion of this paper.

*Revision:* Mean percentage rate of correctly revised models was 99.14% ( $SD = 1.74$ ). There were no differences in the amount of mistakes between the samples ( $p > 0.40$ ). Erroneous problems were excluded from further analyses. We ran Wilcoxon’s tests for each sample, separately. That was to analyze which principle the revision followed. The tests indicated that in the German sample LOs were relocated more frequently than ROs ( $z = -2.95$ ;  $p < 0.01$ ). The same principle was applied by reasoners in the other samples: Russians tested in German in Germany ( $z = -3.83$ ;  $p < 0.01$ ), Russians tested in Russian in Germany ( $z = -3.96$ ;  $p < 0.01$ ), and Russians tested in Russian in Russia ( $z = -4.56$ ;  $p < 0.01$ ). Again, our results suggest similarities across both language groups. There was a clear preference for LO relocations across all samples (figure 2 depicts the results graphically). The principle was equally used by Russian native speakers, who were tested in Russian and in German. This suggests that linguistic aspects were not modulating the effect. Russians tested in Germany as well as

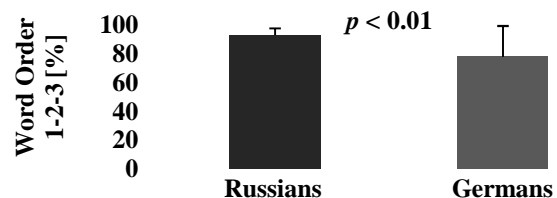


Figure 1. The figure depicts the difference between Germans and Russians during the construction of block arrangements. The word order effect was more pronounced in Russians than in Germans. Error bars indicate standard errors.

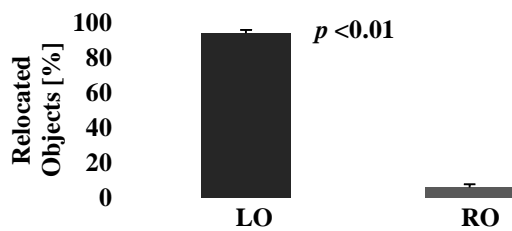


Figure 2. For revision, the LO principle (relocation of the to-be-located object, LO as opposed to the reference object, RO) was preferably applied by participants of all samples. Error bars indicate standard errors.

Russians tested in Russia used the same principle, suggesting similarity across the cultures. We continued our analysis by comparing the magnitude of the preference applied by Germans and Russians in the different settings. The Kruskal-Wallis test revealed that there are no differences between the samples ( $p > 0.30$ ). Unlike the word order effect, the LO effect was equally strong across all groups. This finding further corroborates the assumption of a cross-cultural and cross-linguistic cognitive principle.

## General Discussion

The present study investigates aspects of spatial relational reasoning in reasoners from Germany and Russia. We explored principles applied for the construction and the revision of spatial models in four types of samples. A sample of German native speakers who were tested in German in Germany, a sample of Russian native speakers, tested under the same conditions, a sample of Russian native speakers tested in their mother tongue but in the German cultural environment, and a sample of native speakers of Russian who were naive to the German language, tested in their native Russian cultural environment.

The study was motivated by recent findings that principles applied by German reasoners in spatial relational reasoning tasks were based on linguistic cues. One study (Bucher et al., 2011) suggests that during the physical construction of spatial (block) arrangements, the word order plays a role in guiding the construction process while for the revision of these models the asymmetry of LOs and ROs of relational statements provide the crucial cues for reasoners (Bucher & Nejasmic, 2012; Knauff et al., 2013). Here as a novelty, a similar task was presented to native speakers of Russian. We were concerned with the dissociation of linguistic and cultural aspects. In order to dissociate these aspects to a certain degree, we splitted the Russian group into three sub-samples, allowing a rough distinction of cultural from linguistic influences. The results indicate cross-cultural similarities for both cognitive principles applied during construction and revision of spatial models. Across all samples (German and Russians), the construction followed the word-order-principle. This effect has been previously shown in Germans (Bucher et al., 2011) and could be repetitively shown here. The revision was found to be

guided by the LO-principle. This principle had been repeatedly shown in German reasoners and here – for the first time – in Russians. The effect was comparable in magnitude across all samples. We conclude that both principles reflect similar mechanisms.

However, Germans used the alternative principle (starting construction with the second object) more often compared to the Russian samples and performed thus construction processes more flexible. Please, note that with the current experiment, it is not distinguishable whether reasoners used the first object mentioned in the premise or the LO as a starting point for their construction, because the first object in a statement was identical with the LO. However, Bucher et al. (2011) argue that different cognitive principles are applied during construction (first vs. second object as starting object) and revision (relocation of LO vs. RO), respectively. The authors also provide empirical evidence for their view. The results of the current study show that German native speakers are more flexible when applying the word order principle, compared to Russians, while the LO-principle is applied equally robustly by both groups. This can be taken as corroborating evidence that the cognitive mechanisms underlying construction and revision are distinguishable, however comparable for Germans and Russians.

Nevertheless, we found differences in the manifestations of the word-order effect between the groups. The effect was stronger in Russians compared to Germans. This indicates that Russians used the alternative word order less frequently than Germans did when they constructed their models. When we bear in mind that the Russian language allows for many variations of word orders in a sentence, the result might look counterintuitive, at the first glance. However, we must note that speakers of Russian already make many decisions when they construct a sentence. Maybe, it is the compensation for this “liberty” in the canonical word order of the Russian language which we find reflected by the high adherence to the word order principle. Also important in the present context is that although we might have found cross-cultural similarities between Germans and Russians, as well as cross-linguistic principles that were applied during the construction phase, there is an alternative interpretation of the results. While (as in previous experiments) German reasoners might have based the construction preferably on the word order, it is possible that Russian reasoners applied the LO principle, i.e. put the LO as first object on the table. With the present study we cannot rule out this alternative interpretation but we are currently running experiments designed to look at this problem.

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