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Cross-modal anchoring: magnitude priming based on length leads to contrast effect in numerosity judgment

Abstract: *On one hand, Judgment and Decision Making (JDM) research reports a phenomena called the cross-modal effect, which shows that magnitude priming based on spatial attributes of a stimuli might influence numerical estimations. On the other hand, research directed at human cognition reports that processing of space and numbers may interfere. Despite different theoretical backgrounds, those two lines of research report similar results. Is it possible that the cross-modal anchoring and the interaction between space and number are just two manifestations of the same psychological effect, conceptualized within different paradigms? In Experiment 1 participants were asked to draw lines of different length and estimate numerosity of sets of dots presented for 100 ms. Based on current studies, magnitude priming is assimilated with subsequent numerical judgment. However, an unexpected contrast effect was observed in Experiment 1. Priming of "smallness" resulted in higher estimations of numerosity, while priming of "largeness" was associated with lower estimations. Short exposition time often leads to automatic attention processes, which could possibly account for the observed contrast effect. In Experiment 2 this assumption was tested, verifying potential differences between different exposition times (100 ms vs 300 ms). The same pattern of results was obtained. Findings of both experiments are discussed from the perspective of different anchoring paradigms and concepts related to space and number processing.*

Keywords: *estimations, cross-modal anchoring, numerosity judgment*

Introduction

The anchoring heuristic is a well documented psychological effect (for example Epley & Gilovich, 2010; Furnham & Boo, 2011) that refers to a mechanism in which numerical estimations are biased by different numbers. The classical anchoring effect was proposed by Tversky and Kahneman (1974) – in their seminal study participants had to estimate the percentage of African countries that belong to the United Nations. However, before giving a precise answer a comparative question was asked: is this percentage lower, or higher than 10 (low-anchor condition) or 65 (high-anchor condition). The results showed that within the low-anchor condition the estimates were relatively lower than in the high-anchor condition. The final answers were anchored by the number that was given in the comparative question. This effect could be observed in domaines such as real estate pricing (Northcraft & Neale, 1987), negotiations (Orr & Guthrie, 2005) or medical diagnostics (Dawson & Arkes, 1987). However, recent studies regarding the judgment and decision making have shown that not only numbers may affect numerical estimations.

Oppenheimer, LeBoeuf and Brewer (2008) effectively anchored numerical estimations by asking participants to copy a set of short or long lines before estimating the length of the Mississippi river. Copying a set of long lines lead to higher estimations than copying a set of short lines. Based on the results the researchers suggest that drawing short lines generates a sense of "smallness", which serves as a low-anchor, while drawing long lines generates a sense of "largeness" serving as a high-anchor. This effect, called the cross-modal anchoring, is considered to be a result of magnitude priming caused by drawing the lines. What is more, Tomczak and Traczyk (2017) suggest that stimuli in the form of numbers may affect the estimations due to the physical properties of the stimuli and not the actual value of presented numbers. Tomczak and Traczyk (2017) designed

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a procedure in which participants were asked to draw the same numbers depicted in different physical formats just before the numerical judgment. Results have shown that drawing a number in small physical format (e.g. number 6 drawn as a relatively small object) caused lower estimations than drawing the same number in large physical format (e.g. number 6 drawn as a relatively large object), while the actual number values used in the study (e.g. 6, 27, 216, 2187) did not relate to the magnitude of the estimations. It is crucial to highlight the fact that in this particular procedure magnitude priming was based on the physical size of presented stimuli.

Research regarding a relation between spacial stimuli and numerical estimations is not limited only to the Judgment and Decision Making paradigm. This topic is heavily discussed within the framework of cognition, perception and neural processing, with different theoretical concepts in the context of magnitude systems and processing of different modalities (Walsh, 2003; Lourenco & Longo, 2011). Given that within those two lines of research the results seem to be consistent, in this article we attempt to pertain to theoretical concepts that are beyond the scope of JDM research in order to deepen the understanding of the cross-modal anchoring. In the introduction we describe in detail the psychological effects underlying interference between spatial stimuli and numbers. In summation we present research questions that emerge from the presented theoretical framework.

Generalized magnitude systems

The notion of generalized magnitude system refers to theoretical concept which proposes that different modalities, such as space, number or time, are processed by a common mechanism (Walsh, 2003; Lourenco & Longo, 2011). A Theory of Magnitude (ATOM) proposed by Walsh (2003) attempts to unify findings regarding the possible interaction between the aforementioned modalities, providing a theoretical framework for future studies. Here, we will focus on examples that are directly connected to the cross-modal effect – that is, the connection between space and number.

The argumentation in favor of ATOM focuses on two well-established theories. Mental number line describes a spatial orientation of numbers, which are placed on a metaphorical line oriented from left to right in a growing order (Dehaene, Bossini, & Giraux, 1993; Dehaene, 2003; Izard & Dehaene, 2008). What is more, the process of selecting the greater of two numbers is quicker and more accurate when the distance between the numbers is large, dropping the accuracy and quickness when the distance is small. Many studies have also shown that small number values are associated with the left side and larger values with the right side of space (for meta-analysis, see Wood, Nuerk, Willmes, & Fischer, 2008). This connection between number and space was called a "spatial-numerical association of response codes" (SNARC), which is considered to be a result of aligning numerosities on a mental number line. Further research has shown that there is another connection between numbers and visuo-spatial representations. Zorzi, Priftis and Umiltà (2002) conducted a study which showed that bias observed during the line bisection task, in which participants are asked to place a mark with a pencil through the center of a series of horizontal lines, was also observed in tasks engaging the mental number line.

The term "space" does not define precisely the actual spatial attributes that affect the perception of numbers. However, there is line of research that operationalizes space as length, which is the main attribute of lines used to obtain the cross-modal anchoring. Length interferes with numerosity judgments, that is, judgment referred to the amount or quantity of countable and uncountable objects (e.g. numerosity of a set of dots). Given two arrays of the same number of elements, the longer array is judged to contain more elements than the shorter one (for example Houdé & Guichart, 2001). Moreover, numerosity influences performance on visuo-spatial cognitive tasks even when the numerical information is irrelevant, showing a bilateral dependency. Studies report a systematic spatial bias towards higher numbers when participants are asked to bisect a horizontal line flanked by Arabic digits (Fischer, 2001), as well as biased towards larger quantity when the line is flanked by sets of dots of different numerosity (de Hevia & Spelke, 2009).

From the JDM perspective, study conducted by Oppenheimer, LeBoeuf and Brewer (2008) shows that drawing lines of different length affects numerical estimations in cases such as estimating the length of Mississippi river or mean temperature in Honolulu in July. From the perspective of studies investigating the interference of number and space, perception of length may affect the numerosity judgment. Is it possible that the cross-modal effect and the interaction of space and number are just two manifestations of the same psychological effect, conceptualized within different paradigms? If it is true, drawing lines of different length should effectively anchor the estimations regarding numerosity – drawing long lines should result in higher numerosity estimates than drawing short lines.

Experiment 1

Method

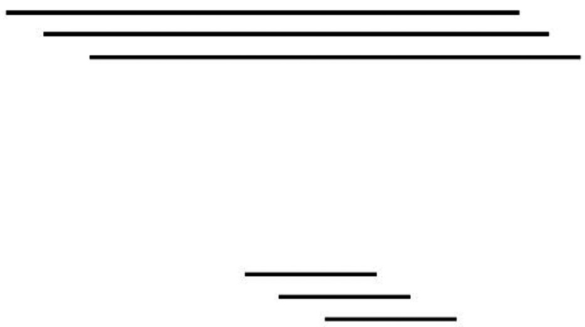
Participants

Fourty-five psychology students participated in the experiment in exchange for course credits. Participants provided informed consent before the experiment. The participation in this study was voluntary, anonymous, and in agreement with the guidelines of the Ethical Committee.

Procedure, stimuli and design

The experiment took place in a room with five computer stands. The computers' screens had a 17 inch display with 1024 × 768 screen resolution. The procedure was a within-subject repeated measures design. Each participant went through conditions with both short and long lines. Five pairs of short and long lines were

Figure 1. Exemplary pair of long and short lines used in the study.

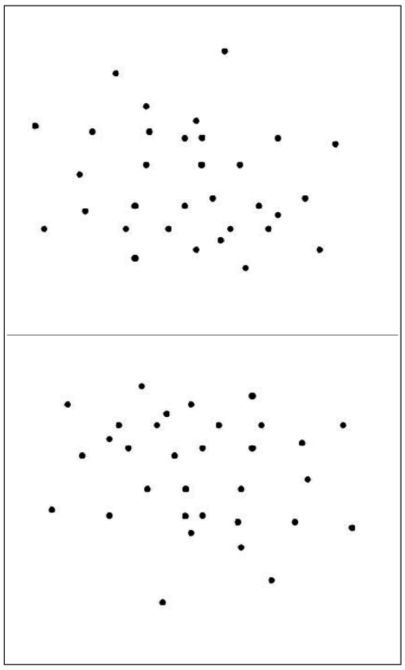


designed for the study. In accordance to procedure used by Oppenheimer, LeBoeuf and Brewer (2008), long lines were at least 3.5 times longer than the short lines (Fig. 1). Exemplary matrices used in the study may be found in Appendix 1.

As for the dependent variable, five pairs of sets of dots of different numerosities were designed. The numerosities were 32, 38, 44, 50 and 56. Gebuis and Reynvoey (2012) indicate several visual cues that affect numerosity estimations, such as convex-hull, density or diameter of dots. That is why each pair of sets of the same numerosity represent exactly the same distribution of dots of the same size, symmetric with respect to the x-axis and y-axis (Fig. 2). This solution allows to preserve exactly the same parameters between the pair of sets of dots.

In the beginning of the experiment participants went through a short training session, which allowed them to practice drawing and get acquainted with exposition time of the sets of dots. The drawing mechanics required using a computer-mouse, similarly to using a pencil in a simple raster graphics editor. Next, participants estimated quantity of five sets of dots (25, 35, 45, 55, 65) presented in random order. Those estimations were not affected by prior manipulation and allowed to determine an individual baseline for each participant. The main experimental procedure consisted of two tasks. Participants were asked to copy the lines as accurately as possible, focusing on their shape and length. After drawing the lines, participants estimated the amount of dots that appeared on the computer screen for 100 ms. Participants typed precise numbers in

Figure 2. Example of the same set of dots of the same numerosity symmetric with respect to the x-axis and y-axis.

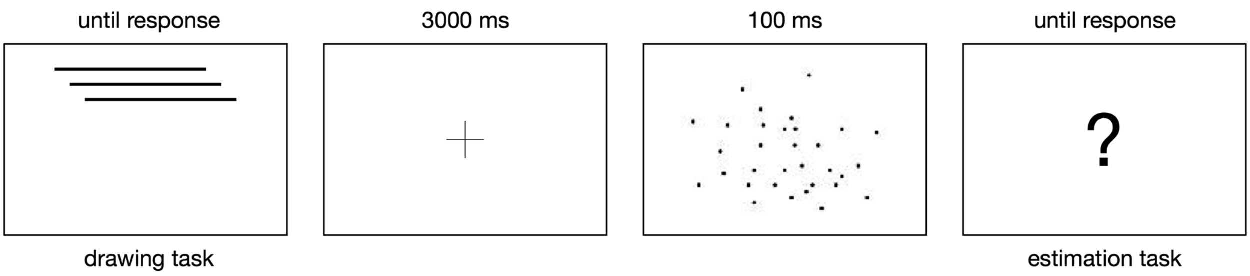


an open-ended text box by using numerical keyboard. There were no restrictions regarding the range of values that could have been typed except that the provided answer had to be a number. Each participant had to complete ten experimental trials in random order, overall drawing both short and long lines before estimating sets of dots of the same numerosity (Fig. 3).

Results and discussion

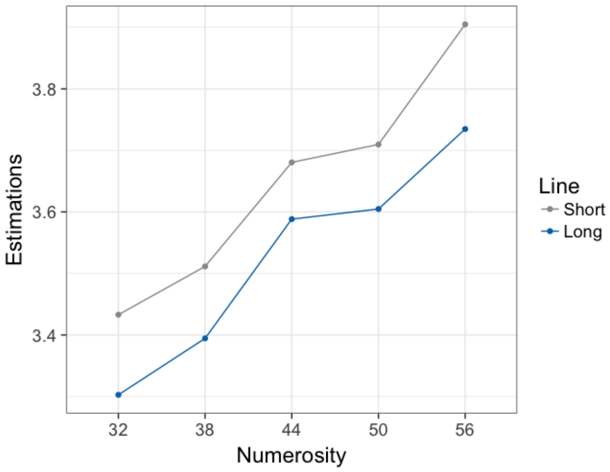
All of the observations were used for the analysis. Due to skewness, all of the estimations were log-transformed. As for accounting for the repeated measures design, subjects and numerosity of sets of dots were defined as random effects. Performed linear mixed models analysis revealed a significant main effect of line $F(1, 405) = 40.124$, $p < .001$) and numerosity $F(4, 405) = 67.712$, $p < .001$. Despite the significant effect of line, the results were contrary to the predictions: drawing long lines caused lower estimations than drawing short lines ($\beta = -0.13$, $p = .003$).

Figure 3. Scheme of one experimental trial. First, participants have to copy a set of line presented on the screen. Then, after the fixation cross, a set of dots is presented for 100 ms. Participants have to estimate the amount of dots that was visible on the screen.



The main effect of numerosity suggests that participants were able to adjust their estimations to the quantity of presented dots – the more dots were presented, the higher were the estimations (Fig. 4).

Figure 4. Results of the Experiment 1. Graph shows that drawing short lines caused higher estimations in every numerosity condition. Pleas note that "Estimations" variable was log-transformed for the analyses and the same variable was used for the graphical representation of the data.



The interaction between line length and numerosity was not significant $F(4, 405) = 0.476$, $p < .753$. What is more, the analysis also included a measures taken from estimations that were made before the main experimental tasks. The mean absolute deviations from the correct amount of dots for each numerosity (25, 35, 45, 55, 65) were used as an additional covariate, proving to be a significant predictor of estimations in experimental tasks $F(1, 45) = 5.93$, $p = .019$. Larger deviations in estimations with no manipulation were connected with higher estimations in the main procedure ($\beta = 0.244$, $p = .019$). Conditional and marginal coefficients of determination were also calculated for the model (Nakagawa & Schielzeth, 2013), resulting in marginal $R^2 = 0.216$ and conditional $R^2 = 0.806$. For the results regarding estimation accuracy during the Experiment 1, see Appendix 2.

The obtained results show a contrast effect between drawing lines of different lines and magnitude of estimations. This effect is contrary to previous findings regarding the cross-modal anchoring. In order to test other possible explanations the length of the drawn lines was investigated. The expected effect could be disrupted if participants did not copy the lines correctly. Nevertheless, this was not the case – the length of the drawn lines differed significantly between conditions $t(296.62) = -32.81$, $p < .001$, with mean length of 232.86 points in short lines condition and 683.95 points in long lines condition.

Another variable that could disrupt the expected cross-modal effect was the exposition time of sets of dots. There is no fixed exposition time that is used consequently in studies regarding numerosity. For instance, exposition time may vary from 80 ms to 100 ms (Dormal & Pesenti, 2007), 150 ms to 450 ms (Vicario, Pecoraro, Turriziani, Koch, Caltagirone, & Oliveri, 2008) or may be fixed at 100 ms (Izard & Dehaene, 2008) or 300 ms (Gebuis & Reynvoet, 2012). Among many possible areas of research, exposition time is crucial for engaging attentional resources. Classical studies (i.e. Reeves & Sperling, 1986; Weichselgartner & Sperling, 1987) report two time-thresholds that are connected with attentional processing – up to 100 ms, in which responses are a result of an automatic attention, and 200–300 ms, which is an indicator of slow and effortful attention. Those results find support in current studies, being still valid while investigated with more advanced methodologies (Carlson, Hogendoor, & Verstraten, 2006) and are used for computational modelling of visual attention (Itti & Koch, 2001). In the context of present study there is one important question emerging from this theoretical framework – since the obtained contrast effect was based on automatic attentional processes, would it still be present when slower and more effortful processes are engaged?

Experiment 2

The main interest of the Experiment 2 is to investigate whether the contrast effect obtained in Experiment 1 would be acquired when slower and more precise attention mechanisms are engaged in processing the dots. Additionally, Experiment 2 will allow to test whether this effect is replicable, or was acquired by random chance.

Method

Participants

Sixty psychology students participated in the experiment in exchange for course credits. Participants provided informed consent before the experiment. The participation in this study was voluntary, anonymous, and in agreement with the guidelines of the Ethical Committee.

Procedure, stimuli and design

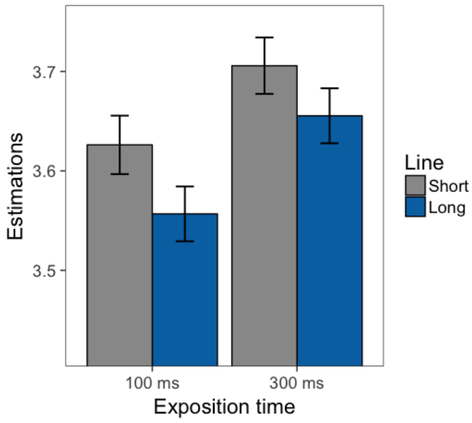
The procedure from Experiment 1 was expanded with additional ten experimental trials. For those trials new sets of dots were designed (numerosities of 32, 38, 44, 50, 56) and five pairs of short and long lines. The procedure consisted of ten trials in which the dots were visible for 100 ms and ten trials with exposition time of 300 ms. The procedure was randomized within each subject.

Results and discussion

All of the observations were used for the analysis. Due to skewness, all of the estimations were log transformed. As for accounting for the repeated measures design, subjects and numerosity of sets of dots were defined as random effects. Performed linear mixed models analysis revealed a significant main effect of line $F(1, 1140) = 15.693$, $p < .001$ and numerosity $F(4, 1140) = 144.508$, $p < .001$. Just like in Experiment 1, drawing long lines was associated with lower estimations ($\beta = -0.069$, $p = .001$). The analysis showed a significant main effect of exposition time

$F(1, 1140) = 35.353$, $p < .001$. When the sets of dots were presented for 300 ms the estimations were higher than in 100 ms condition ($\beta = 0.079$, $p < .001$). However, interaction between line length and exposition time was not significant $F(1, 1140) = 0.404$, $p = .524$ (Fig. 5).

Figure 5. Graph representing magnitude of estimations after copying short and long lines in conditions with different exposition times. Pleas note that "Estimations" variable was log-transformed for the analyses and the same variable was used for the graphical representation of the data.



Those results suggest that despite different exposition times the effect observed in Experiment 1 can not be attributed to automatic and effortless attention processes. Additionally, mean deviations of the estimations from the task preluding the main procedure were used as a covariate, proving to be a significant predictor – $F(1, 60) = 116.765$, $p < .001$. The results are just as in Experiment 1 – larger deviations were connected with larger estimations ($\beta = 0.779$, $p < .001$). Interaction between line length and exposition time was not significant $F(1, 1140) = 0.404$, $p = .524$. For the results regarding estimation accuracy during the Experiment 2, see Appendix 2.

General discussion

The results of Experiment 1 showed that drawing short lines results in higher numerosity estimations than drawing long lines. Those results were contrary to predictions based on the study conducted by Oppenheimer, LeBoeuf and Brewer (2008). Experiment 2 replicated this contrast effect, also showing that lengthening the exposition time of the target of the estimations did not disrupt the pattern. The obtained results are in accordance with the notion that processing length and numerosity may interfere. However, the reported contrast effect could not have been predicted within the proposed theoretical framework. The general discussion will serve as integration of possible perspectives that could serve as a theoretical ground for further research.

From the JDM perspective the possible interference between drawing lines and numerical judgment is documented only when judgment refers to general knowledge (Oppenheimer et al., 2008; Experiment 1, Tomczak & Traczyk, 2017). Tomczak and Traczyk (Experiment 2, 2017) observed an influence of magnitude priming on numerosity judgment, however, their procedure differed from the one used in aforementioned study. First, the sense of magnitude was derived from the presented numbers that differed in physical size. Second, participants were required to draw the numbers on separate pieces of paper. In context of the present study, it is possible that magnitude procedures based on length and size differ in effectiveness. It is also possible that drawing certain stimuli on a separate piece of paper results in different cognitive mechanisms engaged to processing the sets of dots than drawing on a computer screen. Drawing lines within the same surface where the dots appear might result in creating a reference point for the estimations – Gebuis and Reynvoet (2012) point out that visual cues may be crucial in guiding numerosity estimations.

Further explorations of the relation between processing length and numerosity within the JDM paradigm could be based on current knowledge about the anchoring effect. The anchoring mechanism proposed by Oppenheimer, LeBoeuf and Brewer (2008) is based on a certain order and certain characteristic of both dependent and independent variable. First, participants are asked to copy the lines. Next, they have to extract specific information from the memory in order to give answer to the estimation task. The final answer is biased due to magnitude priming. In sum, anchor was given before the estimation target was known. In case of numerosity estimations, this order might have affected the perception of the target of the estimations itself, but not the actual estimations. Cheek, Coe-Odess and Schwartz (2015) conducted a study in which the attempted to anchor the estimations regarding the just finished tasks and behavior. For example, participants were asked to climb a flight of stairs – next, the had to answer whether the climbed more or less stairs than 11 (low anchor) or 35 (high anchor) and estimate the precise number. Thanks to this procedure, participants could experience the target of the estimations before they were faced with the anchor. An interesting question emerges from this line of research – what would be the result of changing the order of the stimuli in case of numerosity judgment? Would it matter if the dots were presented before the drawing task?

Within the paradigm investigating the interference between length and number it is clear that in many cases visual cues influence numerosity judgment (for example Dormal & Pesenti, 2007). It is important to mention that in this line of research dots are often presented as an arrays of different length – the spatial attribute is immanent to the target of estimations. Critcher and Gilovich (2008) proposed an anchoring mechanism that is compliant with this notion – they showed that incidental environmental cues that are embedded within the judgment target may influence the estimations (i.e. when judging willingness to pay, restaurant Studio 17 was considered cheaper than restaurant named Studio 97). Considering both results obtained with visual cues and incidental anchoring, it is possible that the range of situations affected by anchoring based on magnitude priming is much wider than it is currently discussed.

Research shows that visual cues affect numerosity judgment (Gebuis & Reynvoet, 2012). Properties such as convex-hull of the presented set of dots, dots density and diameter, influence the estimations regarding numerosity of the presented set. All of the properties of the sets of dots were the same within the same numerosities. However, there could be differences in subjective perception of convex-hull. Studies investigating attention processes point out that size of the attentional focus may vary depending on the task at hand (for example Castiello & Umiltà, 1990; for review see Carrasco, 2011). Moreover, research suggests a differentiation between extensive and intensive attention (Kolanczyk, 2011). Extensive attention is associated with less strict attention filters which leads to broader scope of attention allowing for creative thinking (e.g. Ansburg i Hill 2003). Intensive attention is associated with particular goal which may result in ignoring objects or events that are not specifically related to the task at hand – following Smith and Kosslyn (2009): it is a dynamic process resulting in higher or lower probability of processing certain locations or objects. In case of the contrast effect obtained in the study, it is possible that the task preluding the numerosity judgment (that is, drawing short or long lines) might have affected the range of visual attention – drawing short lines resulting in smaller attention size than drawing long lines. Perceiving a set of dots with sizable attention range could invoke a subjective impression of smaller convex-hull compared to condition with limited attention range, resulting in lower estimations. Analogically, drawing short lines would limit the size of attention, which could affect the impression of the size of the convex-hull, resulting in lower estimations within the same numerosity. What is more, details in peripheral visual field are often perceived as cluttered, which makes it impossible to differentiate and recognize single objects. This effect is known as crowding effect (for review see Whitney & Levi, 2011). Given that the dots that were not perceived centrally could not be processed sufficiently, the estimations might have been influenced by the magnitude of the clutter. Mechanism such as non-verbal counting (Whalen, Gallistel, & Gelman, 1999) allow to transform imprecise impressions of quantity into precise numbers. Assuming that in the short lines condition the size of attentional focus was actually limited, the amount of the dots in peripheral vision would be higher than with larger attention range. More dots in peripheral vision would result in bigger perceived clutter – allowing to explain the contrast effect observed in this study. However, this notion is purely hypothetical and requires further testing.

If it is the intensive attention that underlies the effects observed in this study, it should be a result of the task that requires participants to draw lines of different lengths. The Ellipses Test is a tool which allows to differentiate between intensive and extensive attention processes (Roczniewska, Sterczynski, Poplawska, Szamotulska, & Kolanczyk, 2011). Moreover, it also provides a measurement of perceptual field search strategy. Hence, using the Ellipses Test could potentially broaden the possible influence of drawing the lines on numerosity judgment. Another interesting approach is to use eye-tracking methodology in order to identify specific eye movement patterns. Depending on the task at hand, the eye-patterns allowing to scan the environment may differ (e.g. Yarbus, 1967). For that reason, drawing lines of different length should be associated with certain occulometric measures related to cognitive engagement and attention (Liversedge & Findlay, 2000; Tsai et al., 2007). Such data would provide an interesting insight to the cognitive processes engaged just before the numerosity judgment.

In sum, the novel findings of this study is that cross-modal anchoring based on magnitude priming derived from length results in contrast effect in numerosity judgment. Study provided more evidence regarding the link between processing length and numerosity. However, the direction of the effect was contrary to results obtained within cross-modal anchoring paradigm based on estimations regarding the general knowledge.

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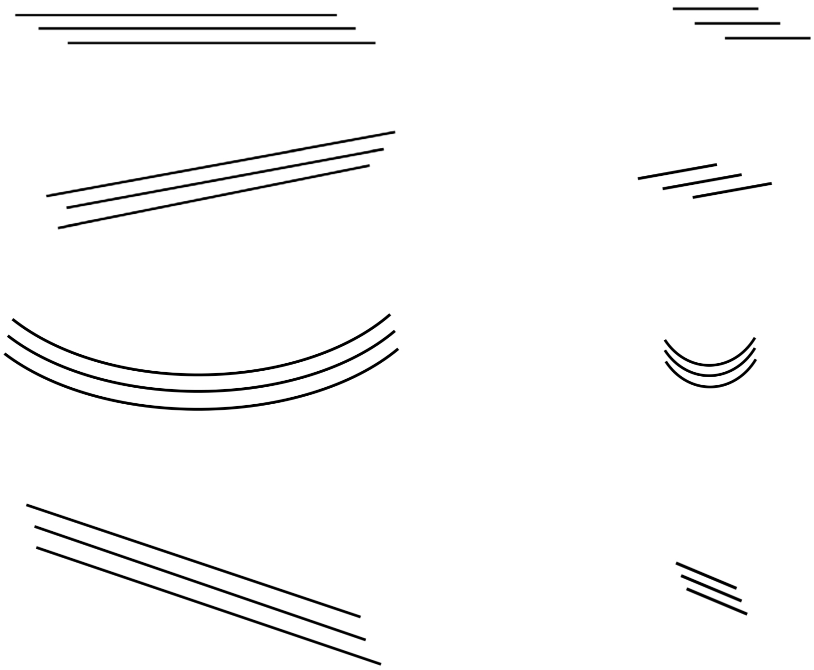
Appendix 1

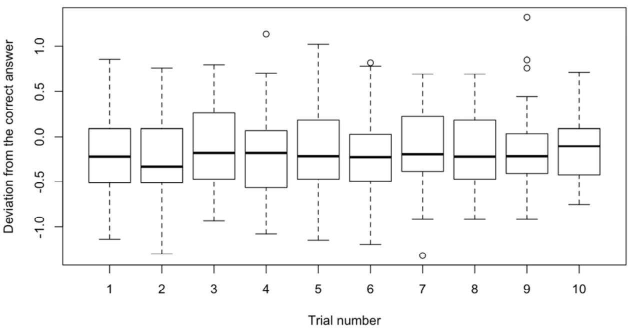


Several matrices of short and long lines used in the study

Appendix 2

Experiment 1

Procedure of the Experiment 1 lasted approximately 5 to 11 minutes ($M = 479.94$ seconds, $SD = 187.04$). Participants did not report any fatigue. However, performed mixed models analysis revealed that there is a relation between the duration of the study and the deviation from the correct answer [$\beta = 0.007$, $SD = 0.003$, $p = .03$]. However, the obtained marginal R^2 is very low (0.002), which suggests that the revealed effect is not reliable. What is more, graphical representation of the data shows that there is no particular relation between experiment duration and provided estimates. Please note that deviation refers to responses after log transformation. The $\beta = 0.007$ translates to approximately 0.3 points of raw data.



Experiment 2

Procedure of the Experiment 1 lasted approximately 7 to 15 minutes ($M = 693.31$ seconds, $SD = 248.35$). Participants did not report any fatigue. However, performed mixed models analysis revealed that there is a relation between the duration of the study and the deviation from the correct answer [$\beta = 0.025$, $SD = 0.001$, $p < .001$]. The obtained marginal $R^2 = 0.1$, which suggests than in case of Experiment 2 the relation between time and estimations may actually be valid. Please note that deviation refers to responses after log transformation. The $\beta = 0.025$ translates to approximately 1 point of raw data. What is interesting, testing whether participants provide more accurate numerosity estimates over the course of the experiment is not usually performed (e.g. Gebuis & Reynvoet, 2012; Patalano et al., 2015). For that reason, it is an interesting direction for future studies.