Does Presentation Format Modulate Adults' Automatic Processing of Proportions?

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Abstract

Whereas much is known about how humans categorize and reason based on absolute quantities, research investigating the processing of relative quantities, such as proportions, is comparatively limited. The current study used a Stroop-like paradigm to examine adults' automatic processing of nonsymbolic proportions and how presentation formats modulate this processing. Participants were asked to compare individual components across proportions in six different presentation formats. Congruity between component size and overall proportion affected accuracy of comparison, such that participants were less accurate when proportion (the irrelevant dimension) was incongruent with absolute quantity (the relevant) dimension. Moreover, the congruity effect was modulated by the presentation format. These findings serve as evidence that humans automatically access relative quantity when presented in nonsymbolic formats and provide evidence that the strength of this processing is modulated by the format of presentation.

Keywords: automatic processing; congruity effect; relative quantity; proportions; presentation format

Introduction

Humans share with many species a non-verbal system to estimate absolute quantity (Dehaene, 1997). The invention of number symbols allows humans to precisely represent absolute quantity instead of mere approximate estimation. However, simple absolute quantification is often not sufficient to guide behavior. We frequently need to relate two quantities to generate a new construct: proportion or ratio. Although much is known about the processing of absolute quantity (either symbolic or nonsymbolic), comparatively little is known about how the brain encodes relative quantity.

To represent relative quantity accurately, humans exploit their symbolic numerical competence by using number fractions. However, children and adults often experience great challenges and difficulties in learning and using fractions (Ni & Zhou, 2005). Furthermore, research on symbolic fractions suggest that the numerical magnitudes represented by symbolic fractions are not automatically activated (Kallai and Tzelgov, 2009), and that the holistic processing of symbolic fractions depends on the stimuli and task contexts (Meert et al., 2009; Meert et al., 2010; Schneider & Siegler, 2010). For example, Meert and colleagues (2009) observed that access to the magnitude of symbolic fractions was affected by the congruity or incongruity between the value of the single components and the value of whole fraction. Schneider and Siegler (2010) found that adults process fraction magnitudes holistically when the task does not allow them to use any shortcut strategies that would enable separate processing of the numerator and denominator magnitudes.

Similar to absolute quantity, which can be judged approximately without symbols, proportion (relative quantity) can also be determined non-verbally. Studies have suggested that even by a young age, humans can understand proportion information when presented nonsymbolically (McCrink & Wynn, 2007; Jacob, Vallentin, & Nieder, 2012; Matthews, Lewis, & Hubbard, 2015). For instance, infants can discriminate between two ratios long before the concept of proportionality is introduced during formal schooling (McCrink & Wynn, 2007).

Research even suggests that the magnitudes of proportions are automatically activated (Duffy, Huttenlocher, Levine, 2005; Duffy, Huttenlocher, Levine, & Duffy, 2005; Fabbri et al., 2012; Yang et al., 2015; Matthews & Lewis 2016). Six-month-olds dishabituated when the relation between a dowel and its container changed but not when the absolute size of both object changed while the relation was held constant (Duffy, Huttenlocher, Levine, & Duffy, 2005). Moreover, 4-year-olds chose the dowel which had the same dowel-container relation as the original display rather than the one with the same absolute dowel size (Duffy, Huttenlocher, Levine, 2005). Fabbri et al. (2012) found that the magnitude of proportions can be automatically and holistically processed by adults using a congruity manipulation in which the greater numerosity of white dots co-occurred with a lower proportion. Yang et al. (2015) found that proportion interfered with preschool children's area comparison performance.

It is acknowledged that the cognitive processes involved in proportion processing vary depending on the type of proportional relation involved (i.e., part-to-part vs. part-to-whole) (Sophian & Wood, 1997; Spinillo & Bryant, 1999; Möhring, Newcombe, Levine, & Frick, 2016), and display types (i.e., continuous, discretized, discrete) (Spinillo & Bryant, 1999; Jeong, Levine, & Huttenlocher, 2007; Boyer, Levine, & Huttenlocher, 2008).

Proportions can be presented as either part-to-part relations or part-to-whole relations. Previous research suggested that part-to-part presentation is easier for 6- to 8-year-old children (Spinillo & Bryant, 1999). However, other study provided evidence that children performed better for problems involving part-to-whole presentation (Sophian & Wood, 1997; Möhring, Newcombe, Levine, & Frick, 2016). There is no evidence yet for if and how adults would perform differently for these two relations presentation.

Proportions can also be displayed as continuous, discrete, or discretized (see Figure 1). Previous studies generally agreed that continuous display encourages perceptual approximate measurement of the intensive quantity, while discrete (and discretized) display would lead to exact counting strategy (e.g., Boyer, Levine, & Huttenlocher, 2008; DeWolf, Bassok, & Holyoak, 2015). This was underlined by findings that children showed greater and earlier success in judging proportions displayed as continuous quantities than in judging proportions displayed as discrete quantities even if other variables were controlled to be constant (Spinillo & Bryant, 1999; Jeong, Levine, & Huttenlocher, 2007; Boyer, Levine, & Huttenlocher, 2008). For adults, we do not know yet whether they are still influenced by the display format.

These results suggest that presentation format might influence proportions processing. Fabbri and Yang's results are actually different as for the level of automaticity. It is probably due to the fact that they used different presentation format. Fabbri et al. (2012) used arrays of dots and part-to-part proportion judgment, while Yang et al., (2015) asked participants to compare the areas of two sectors that were designed in part-to-whole relation. Therefore, the present study aims to systematically investigate how the level of automaticity will change for different presentation formats.

The current study used a Stroop-like paradigm to examine the processing level of proportions. In a Stroop-like task, participants are asked to make judgments on one dimension while there are other dimensions that may agree or conflict with the one to be judged. Participants' performance can suggest the automatic activation of the irrelevant dimensions. Higher error rate and longer reaction times will be observed for incongruent trials than for congruent trials if the irrelevant dimensions are accessed automatically. For example, people tend to spend more time and make more errors when they are asked to compare the magnitudes of two numbers that have incongruent physical sizes than the pairs that have congruent physical size with corresponding magnitudes (Henik & Tzelgov, 1982).

In the present study, absolute quantity will be treated as the relevant dimension and relative quantity (proportion) as the irrelevant dimension. For congruent trials, the larger proportion also has the larger components. For incongruent trials, the larger proportion would have the smaller components. If participants' performance is worse in the incongruent condition, it would provide evidence that the representation about proportions is automatically activated.

We aim to investigate whether presentation format of proportions would be automatically activated in different levels and thus have different effects to the absolute quantity comparisons. The size of interference in Stroop-like tasks is proposed to be a function of degree of the irrelevant dimension's automaticity (MacLeod & Dunbar, 1988). Therefore, we focus on the size of interference to see whether the automatic accessing level of proportions will differ.

Method

Participants

33 undergraduate students from a large Midwestern university participated for course credit (31 females; ages 18 – 22).

Stimuli

Presentation formats were designed to be all possible combinations of display types and relation types.

Three display types were designed: continuous, discrete, and discretized (see Figure 1). The discrete items were arrays of white and black squares with width of 20 pixels. The discretized items were displays composed of these squares stacked to form line segments, except that they were lined together with 1 pixel distance between them. The continuous items were identical to the discretized displays except that there was no space in between.

We examined both part-to-part and part-to-whole relations. For all three displays, we varied the presentation such that half of the proportions were presented in part-to-part relation, and half were presented in part-to-whole relation. The part-to-part relation was defined as the white portion to the black portion; the part-to-whole relation was defined as the white portion to the total portion.

Each proportion was presented in one of the six presentation formats depicted in Figure 1 below.

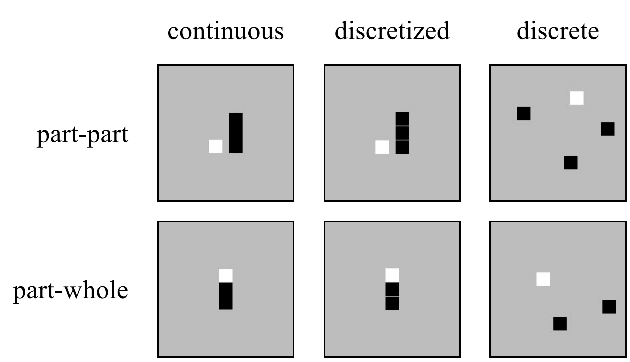

Figure 1: Example of six presentation formats used in the experiment, all represent proportion of 1/3.

Each stimulus pair consisted of two proportions displayed side by side. The center-to-center distance between the two proportions was 800 pixels.

There were two conditions differing by congruity. In congruent pairs, the stimulus which had the larger white portion also had a larger proportion value of white portion relative to either black portion or total (white plus black) portion. In incongruent pairs, the stimulus which had larger white portion had a smaller proportion value of white portion relative to either black portion or total (white plus black) portion. Table 1 showed all the stimuli used.

Table 1 Stimuli used in the present study

	Prop. 1	Prop. 2	Absolute Distance	Relative Distance
congruent	2/8	3/9	1	1/12
	1/4	2/6	1	1/12
	1/6	2/8	1	1/12
	2/3	3/4	1	1/12
	4/12	5/12	1	1/12
	7/12	8/12	1	1/12
	2/12	3/9	1	1/6
	1/6	2/6	1	1/6
	1/12	2/8	1	1/6
	3/9	4/8	1	1/6
	4/6	5/6	1	1/6
	5/10	6/9	1	1/6
	4/8	6/9	2	1/6
	2/4	4/6	2	1/6
	1/6	3/9	2	1/6
	3/9	5/10	2	1/6
	2/6	4/8	2	1/6
	1/3	3/6	2	1/6
incongruent	1/3	2/8	1	1/12
	2/6	3/12	1	1/12
	1/4	2/12	1	1/12
	3/4	4/6	1	1/12
	5/6	6/8	1	1/12
	6/9	7/12	1	1/12
	6/8	7/12	1	1/6
	1/3	2/12	1	1/6
	5/6	6/9	1	1/6
	4/6	5/10	1	1/6
	2/3	3/6	1	1/6
	2/4	3/9	1	1/6
	4/6	6/12	2	1/6
	2/3	4/8	2	1/6
	1/2	3/9	2	1/6
	2/4	4/12	2	1/6

Note. Prop. 1 means the first proportion value; Prop. 2 means the second proportion value. Absolute Distance means the absolute quantity distance, which is the difference for the white portions of the pair; Relative Distance means the relative quantity distance, which is the difference for the proportion values of white portion relative to either black portion or total (white plus black) portion.

Procedure

Participants were instructed to select the stimulus which had larger white portion. Participants were asked to press "d" when they judged the left stimulus had larger white portion and to press "j" when they judged the right stimulus had larger white portion. Both speed and accuracy were emphasized in instructions.

Each trial began with a 500 ms presentation of a fixation cross in the center of the screen, immediately followed by the stimulus pair. The pair stayed on the screen until participants submitted a response or timed out at 3000 ms.

In each block, each of these 34 proportion pairs was presented twice, either with the larger proportion to the left or to the right, giving 68 trials in each block. The stimuli in each block were presented in a random order. There were six different blocks, and the presentation order of these six blocks was counterbalanced, resulting a total of 408 trials.

Results

Accuracy and mean reaction time (RT) were computed for each condition for each participant and used as the primary outcome variables. Only correct RTs were used in the analysis. We conducted separate repeated-measures ANOVAs using accuracy and RT.

The repeated-measure ANOVA on the accuracy with congruity and presentation format as within-subject factors was calculated. Results revealed that the main effect of congruity was significant, F (1, 32) = 15.827, p = 0.000, η_p^2 = 0.331. Participants made more mistakes in the incongruent condition (M = 77.1%, SE = 4.6%) than in the congruent condition (M = 92.0%, SE = 1.3%). The main effect of presentation format, however, was not significant, F (5, 160) = 0.184, p = 0.671, η_p^2= 0.006. This indicated that adults' overall accuracy was not affected by presentation formats. Figure 2 depicted the pattern of accuracy for congruent and incongruent conditions for each presentation format.

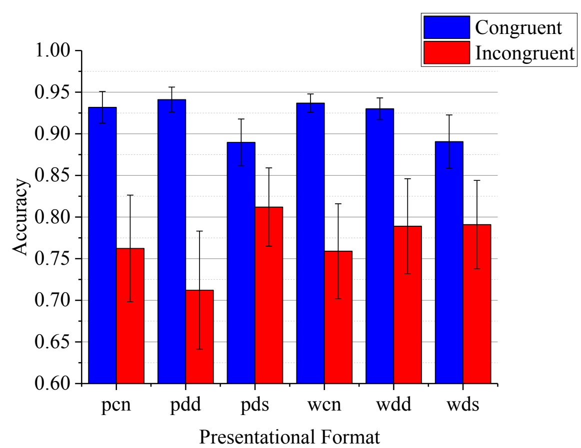

Figure 2: Congruity effect on accuracy for each presentation format. "pcn" means part-to-part relation with continuous display; "pdd" means part-to-part relation with discretized display; "pds" means part-to-part relation with discrete display; "wcn" means part-to-whole relation with continuous display; "wdd" means part-to-whole relation with discretized display; "wds" means part-to-whole relation with discrete display.

The two-way interaction of presentation format with congruity was significant, F (5, 160) = 2.319, p = 0.046, η_p^2= 0.068. The result indicated that the effect of congruity was modulated by presentation format.

We also analyzed reaction times in the same way as accuracy. Figure 3 displays the pattern of mean correct reaction times across conditions. Only the main effect of presentation format was significant, F (5, 105) = 7.575, p = 0.000, η_p^2= 0.265. The main effect of congruity and the two-way interaction of congruity and presentation format were not significant, ps > 0.05.

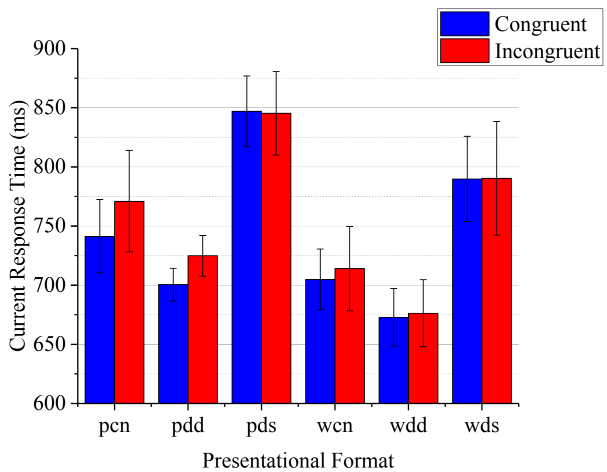

Figure 3: Congruity effect on response times for each presentation format.

Discussion

The results of current experiment showed that adults made more mistakes making judgments in the incongruent conditions than in congruent conditions. And the size of congruity effect varied by different presentation formats. But response time did not show such a clear pattern as accuracy. Participants seemed to spend about same time comparing congruent and incongruent trials. Overall, the current study suggested that adults can automatically process the magnitudes of proportions even though it was irrelevant and disturbing to the absolute quantity comparison task, and that the congruity effect was modulated by the presentation format.

Even though more and more effort has been made to explore human's understanding of proportions, very little is known about the specific processing level of them. Consistent with previous findings that human have an intuitive understanding of proportion and represent them perceptually (e.g., Jacob, Vallentin, & Nieder, 2012; Matthews, Lewis, & Hubbard, 2015), our study demonstrated that proportions can be automatically processed. The observation of the congruity effect confirmed the findings of previous studies that showed the same automatic processing of proportion (e.g., Fabbri et al., 2012; Yang et al., 2015; Matthews & Lewis 2016). The study also provided evidence to the fact that humans, at least adults, can process proportion automatically no matter what kind of formats the proportion is presented.

Moreover, based on previous findings that presentation format can influence proportion processing, the present study found that the level of automatic processing of proportion varied for different presentation formats. The size of congruity effect of automatic processing of proportion was modulated by presentation format. Proportions presented as discretized part-to-part display seemed to show the largest difference of accuracy for congruent trials and incongruent trials. This finding was a little bit surprising, because previous studies suggested that continuous display promotes greatest success for proportion processing at least for children (Boyer, Levine, & Huttenlocher, 2008). It is possible that adults adopt different processing strategies or preference than children. It would be interesting to see whether children shown different congruity effect pattern for these presentation formats. Another possibility is that the task in the current experiment was an implicit and unintentional task for proportion processing, while previous studies showing presentation differences were all explicit and intentional tasks for proportion processing (Sophian & Wood, 1997; Spinillo & Bryant, 1999; Jeong, Levine, & Huttenlocher, 2007; Boyer, Levine, & Huttenlocher, 2008). Humans might perform differently during two task scenarios. Further studies will be needed to address these issues.

Theorists generally have two different explanations to account for the mechanism of automaticity phenomenon. Some focus on the learned automatic processes and emphasize the learning mechanism (Anderson, 1992). Others believe there are innate automatic processes that humans are born with (Hasher & Zacks, 1979). The current study cannot tell whether the mechanism of the automatic processing of proportion is natured or nurtured. 5-year-old children have been found to show similar congruity effect for accuracy but not response time in a sector comparison task, which provided some hint that the automatic processing of proportion is not acquired by learning or instruction (Yang et al., 2015). However, more evidence considering culture, education and intelligence, is required to reach final conclusions about the mechanism of automatic processing of proportion.

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