Mental Comparisons of Magnitudes: Numerical vs. Graphical Format

Martin Galilée
Laboratory of Educational Sciences, Univ. Grenoble Alpes, France
Martin.Galilee@univ-grenoble-alpes.fr

Erica de Vries
Laboratory of Educational Sciences, Univ. Grenoble Alpes, France
Erica.deVries@univ-grenoble-alpes.fr

Neil H. Schwartz
California State University, Chico, CA, USA
NSchwartz@csuchico.edu

Abstract. Like numbers, lengths, and durations, values of energy consumption are magnitudes. A magnitude can be presented in graphical or numerical format. Numerical and offline cognition research suggest that presentation format affects internal representations and offline cognitive processes, making different formats better suited for different tasks. In an empirical study on 92 participants, we determined that presenting energy consumption in a numerical format was better suited for direct recall, whereas a graphical format was better suited for offline mental comparisons. This confirms the hypotheses and suggests the use of graphical rather than numerical presentation formats for energy consumption.

Keywords: Magnitude; learning; mental comparisons; offline cognition; home energy consumption.

Introduction

Numerous devices are designed to monitor one's home energy consumption using numerical as well as graphical format, but the influence of representational format has not been systematically investigated. In the present study, we sought to determine whether representational format has an effect on cognitive processing of magnitude.

Like numbers, lengths, and durations, values of energy consumption are magnitudes. According to the current consensual view, all magnitudes are processed similarly in the mind and by the same brain structures (Walsh, 2003). However, numerical cognition research has shown that distinct forms of internal numerical representations are accessed for particular functions, as described for instance in Dehaene's (1992) *triple-code model*, in which an Arabic code, a verbal code, and an analogue magnitude code coexist. Particularly, the latter code is thought to be used for estimation tasks, and is compared to a length on a mental *number line*. For Cohen Kadosh and Walsh (2009), internal numerical representation is not fully abstract, if at all, and is sensitive to presentation format.

Empirical studies on numerical representations mostly investigate online cognitive processes – participants directly responding to presented stimuli. However, in the absence of stimuli, people resort to offline cognitive processes operating on prior knowledge. Kosslyn and colleagues (1977) studied offline mental comparisons, using drawn stickmen of different sizes. Their experiments yielded the finding that internal representations used for offline mental comparisons (a) were homomorphic to their sensory counterpart and (b) used the same cognitive processes as in online cognition. In other words, when asked which of two stickmen was larger, participants mentally pictured both and compared their sizes by "looking at them" with the eye of the mind.

We hypothesize that, in magnitude learning, a representational format gives rise to a homomorphic mental representation, accompanied or not by a concomitant abstract mental representation. The homomorphic mental representation is used in subsequent mental tasks involving this magnitude. We contend that numerical format yields better results at recall tasks because of its verbal nature, whereas graphical format facilitates estimation and comparison tasks because it provides, on such graphical tasks, a readily visible answer with no need for computation (see Larkin & Simon, 1987).

In the present study, we use the energy consumption of appliances as magnitude and both direct recall and mental comparisons as dependent variables. We expect to find more accurate recall in the numerical condition and faster comparisons in the graphical condition.

Method

Participants were N = 98 and 78 % female. Average age was 22 years ($SD = 4.09$). Participants entered a computer lab in groups of up to 12 people, were randomly assigned to the numerical or graphical format condition, and were presented with the pictures and descriptions of eight fictitious appliances. Using a flashcards computer program, participants learned the appliances' energy consumption in either numerical format (three-digit numbers ranging from 147 to 701) or graphical format (vertical bar ranging in size from 24 mm to 113 mm) and recalled the energy consumption six times by typing numbers in the numerical condition or by scaling a bar with the mouse in the graphical condition. A learning score was calculated from the last three recalls of each appliance. Then, participants completed a comparison task where they had to select with the keyboard which of two appliances presented on the screen used most energy. Because only the pictures of the appliances were presented, the comparisons of energy consumptions were made from memory and not from direct visual input, making the comparisons offline mental tasks. Participants completed a total of 112 comparisons. Their Response Time (RT) and the correctness of their answers were recorded.

Results

Were removed from analyses (a) 5 participants with too few correct answers on the comparison task, (b) RTs that were either below human perceptual reaction time (160 ms), or 2.5 *SD*s above the participant's average RT, and (c) the appliances with lowest and highest consumption which were prone to categorization effects (Kosslyn et al., 1977).

For each participant, the error percentages of all energy consumption recalls were averaged to constitute the Recall score. An ANOVA on Recall yielded significant results for Format, $F(1, 92) = 28.61$, $p < .001$, $\eta^2 = .24$, indicating that in the numerical condition ($M = 7.89$, $SD = 11.30$), participants recalled energy consumption value more accurately than in the graphical condition ($M = 21.33$, $SD = 12.70$).

The comparisons were split into three categories according to the numerical distance (small, moderate, large) between the energy consumption of the appliances. Accordingly, for each participant, three RT scores were calculated by averaging the response times of correct answers within each distance group. We ran a 3 (Distance) x 2 (Format) ANOVA on RT. We found a significant main effect of Format, $F(1, 91) = 18.89$, $p < .001$, $\eta^2 = .17$, indicating that participants in the Graphical condition responded faster ($M = 1307.97$, $SD = 73.09$) than participants in the Numerical condition ($M = 1775.09$, $SD = 73.82$). We found a significant main effect of numerical distance, $F(1, 91) = 48.28$, $p < .001$, $\eta^2 = .36$, showing reduced RTs for larger numerical distances. Importantly, an interaction was found, $F(2, 90) = 3.128$, $p = .049$, $\eta^2 = .07$, indicating that numerical distance influenced RTs differently according to the presentation format used in the learning phase.

Participants in the Numerical condition showed longer RTs specifically for small numerical distances, whereas, in the graphical condition, numerical distance seemed to affect RTs more linearly (Table 1).

Table 1: Response Times (ms) according to Format and Numerical Distance.

	Numerical		Graphical	
	M	*SD*	*M*	*SD*
Small distance	2028	801	1455	545
Moderate distance	1644	516	1259	408
Large distance	1653	612	1210	372

Conclusion

In accordance with our hypotheses, we observed that learning a magnitude in a graphical format, as opposed to numerical, hindered recall performance but supported performance in an offline mental comparison task, confirming that different presentation formats lead to better results at different offline tasks. Moreover, the interaction found between presentation format and numerical distance suggests that different presentation formats lead to different cognitive processes even on the same task, although our experimental setting does not allow us to infer their nature in either condition. This nonetheless supports the idea that internal magnitude representations are not abstract, and possibly homomorphic to sensory stimuli. Also, this confirms that presentation format effects observed with online cognitive tasks can also be found in offline tasks, suggesting that information is stored in memory in the format provided by the original sensory stimulus.

For the design of energy consumption tools, these results suggest that graphical representations may be harder to learn accurately but may enable users to make decisions about energy without needing a cheat-sheet, effectively enabling offline cognition and freeing users from the tool once learning is achieved.

Acknowledgements

During this work, the first author of this paper held a doctoral fellowship from Région Rhône-Alpes.

References

Cohen Kadosh, R., & Walsh, V. (2009). Numerical representation in the parietal lobes: abstract or not abstract? *Behavioral and Brain Sciences*, *32*(3-4), 313–328.

Dehaene, S. (1992). Varieties of numerical abilities. *Cognition*, *44*(1-2), 1–42.

Kosslyn, S. M., Murphy, G. L., Bemesderfer, M. E., & Feinstein, K. J. (1977). Category and continuum in mental comparisons. *Journal of Experimental Psychology: General*, *106*(4), 341.

Larkin, J. H., & Simon, H. A. (1987). Why a Diagram is (Sometimes) Worth Ten Thousand Words. *Cognitive Science*, *11*(1), 65–100.

Walsh, V. (2003). A theory of magnitude: common cortical metrics of time, space and quantity. *Trends in Cognitive Sciences*, *7*(11), 483–488.