



Spacing and Presentation Modes Affect the Unit-Decade Compatibility Effect During Number Comparison

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Abstract: The unit-decade compatibility effect has challenged the model of holistic number magnitude processing, suggesting decomposed processing of multi-digit numbers. Recent evidence confirms that decomposed processing of decade and unit magnitudes occurs in parallel. However, the mode of presentation of multi-digit numbers may affect the processing mode (holistic vs. decomposed, parallel vs. sequential). We therefore investigated in two studies, whether presentation mode (vertical, horizontal, or consecutive) or the distance between two vertically presented numbers affects the unit-decade compatibility effect during number comparison. We found that the compatibility effect did not differ significantly between vertical and horizontal presentation, adding to previous results on perceptual generality, but was nonsignificant with consecutive presentation. However, the compatibility effect was significantly smaller, if numbers are spaced further apart. Thus, stimulus size and distance between numbers affect the processing of multi-digit numbers and should be reported in future studies.

Keywords: number magnitude processing, hybrid model, unit-decade compatibility effect, presentation mode

It is a long-lasting debate in the number processing literature, whether the magnitudes of multi-digit numbers are processed as a whole (holistically) or in a decomposed fashion, that is, units, decades, hundreds, etc., separately.

The holistic model states, that when comparing a number pair consisting of 2 two-digit numbers, these are first represented as a whole on a mental number line, then compared to each other (Brysbart, 1995; Dehaene, Dupoux, & Mehler, 1990). The decomposed model by Nuerk, Weger, and Willmes (2001) suggests multiple number lines. In the case of two-digit numbers, two number lines, one for units, and one for decades, are proposed. Unit and decade digits of both numbers are compared separately along these number lines. A strong argument for the theory of decomposed processing is the so-called unit-decade compatibility effect (Nuerk et al., 2001).

In compatible number comparison items, the larger number contains the larger unit digit (e.g., 65–87; $6 < 8$; $5 < 7$). In incompatible number comparison items, the larger number contains the smaller unit digit (e.g., 59–81; $1 < 9$, but $8 > 5$). The overall difference between both number pairs is 22. However, the reaction time to spot the larger number is shorter with the compatible example compared to the incompatible example. Such an effect can only occur in a decomposed model of number magnitude processing, since

the mental number-line representation of the holistic model would predict equal reaction times across all two-digit number pairs with the difference of 22. If however only the whole number magnitudes were compared, a unit-decade compatibility effect should not occur at all.

It was originally argued (Poltrock & Schwartz, 1984) that such decomposed comparison occurs sequentially, that is decades are compared before units are compared. If numbers were compared decomposed, but sequentially, a decision could be made immediately after the decade comparison. This should however, elicit faster reactions in incompatible than in compatible items, since decade distance is larger in incompatible number pairs of the same distance and items with larger distance are compared faster than items with smaller distance (Nuerk et al., 2001; Pletzer, Kronbichler, Nuerk, & Kerschbaum, 2013). Thus, it is assumed that decomposed processing of units and decades occurs in parallel, which is supported by recent eye-tracking evidence (Moeller, Fischer, Nuerk, & Willmes, 2009).

However, the universality of the unit-decade compatibility effect has been challenged by two lines of research. On the one hand, interindividual differences in the compatibility effect have been reported, suggesting interindividual differences in the preferred mode of processing number magnitudes. We were recently able to demonstrate that

sex might be one factor accounting for such interindividual differences. While men showed no compatibility effect in reaction times (RT) in a two-digit number comparison task, women did show a significant compatibility effect in RT. Since previous results suggest that men in general tend to preferably process global aspects of hierarchical stimuli, whereas women preferably process local aspects of hierarchical stimuli (Kramer, Ellenberg, Leonhard, & Share, 1996; Pletzer, Petasis, & Cahill, 2014; Razumnikova & Vol'f, 2011; Roalf, Lowery, & Turetsky, 2006), we interpreted this as evidence that men compare the two numbers according to the holistic model, whereas women compare the two numbers according to the decomposed model (Pletzer et al., 2013).

On the other hand, it has been criticized that the compatibility effect might be elicited by the presentation mode of stimuli. Studies using comparison of numbers to a fixed standard instead of a simultaneous presentation mode usually do not find a compatibility effect (e.g., Brysbaert, 1995; Dehaene et al., 1990). In that respect, it has also been demonstrated that consecutive presentation of number pairs, as common in studies with fixed standards, does not elicit a compatibility effect (Ganor-Stern, Pinhas, & Tzelgov, 2009; Zhou, Chen, Chen, & Dong, 2008) except if a very high number of within-decade pairs (e.g., 51–57) emphasizes the importance of units for the comparison (Moeller, Fischer, Nuerk, & Willmes, 2013). Consecutive presentation prevents both parallel and sequential decomposed comparison and forces participants to process the whole number magnitude of one number before comparing it to the other number.

Furthermore, the vertical presentation of numbers above each other may visually facilitate the separate comparison of decades and units, especially since digitwise addition and subtraction of multi-digit numbers is taught in vertical presentation mode in schools. In an experiment of Nuerk, Weger, and Willmes (2004), numbers were presented diagonally above each other and they still observed a significant compatibility effect. However, it could be argued that diagonal presentation still contains a vertical element and does not fully address the issue with vertical presentation modes. No study has up to now used a completely horizontal presentation mode to study the compatibility effect. Furthermore, the previous study by Nuerk et al. (2004) did not directly compare the size of the compatibility effect between different presentation modes in the same sample but rather reported, that a significant compatibility effect could be observed with the diagonal presentation mode.

Moreover, no study has so far addressed the question, whether different spacing between numbers in the vertical presentation mode affects the size of the compatibility effect. Spacing effects on equations suggest that it is harder to solve mathematical problems if the operands are spaced

closer together than if they are spaced farther apart (Jiang, Cooper, & Alibali, 2014; Kirshner, 1989). Landy and Goldstone (2007a, 2007b, 2010) extended these works and varied the spacing according to the syntactic structure of the equations. For example, in equations involving both additions and multiplications, multiplications are supposed to be solved first. Participants tended to follow this rule more closely and made smaller errors in solving the equations, if multiplications were spaced closer together than additions. Thus, if the two numbers of a number comparison item are presented very closely together, participant may tend to compare the single digits first than to evaluate the whole number magnitudes before comparing the numbers. Furthermore, with increasing distance between numbers the similarity to multi-digit addition and subtraction should decrease and each number should be more strongly perceived as a separate entity than as part of a single item. Thus, closer spacing of numbers should increase, while wide spacing of numbers should decrease the compatibility effect.

If a different presentation mode can reduce the compatibility effect, this suggests that the processing mode can be changed either from decomposed to holistic comparison or from parallel to sequential decomposed comparison. If a different presentation mode were to reverse the compatibility effect, this would be strong evidence for a change to sequential comparison. Thus, either participants choose a processing mode (holistic vs. decomposed, sequential vs. decomposed parallel) that is most suitable for the task at hand, or holistic and decomposed processing occur simultaneously and – depending on the presentation mode – influence the results to a different extent. The latter idea is consistent with the hybrid model of number processing, which attempts to unite the holistic and decomposed model and encompasses all behavioral effects during number comparison (distance, compatibility, problem size) (Nuerk et al, 2001; Verguts & De Moor, 2005). Importantly, effects of stimulus characteristics, including spacing, have also been reported for other types of hierarchical stimuli (Martin, 1979; Navon & Norman, 1983) to influence the general tendency to process stimuli at the global or local level.

In order to evaluate, whether the size of the compatibility effect is modulated by presentation mode and spacing, two studies were performed. Since our previous study demonstrated sex effects on the compatibility effect, only male participants were included in these studies.

In the first study the simultaneous vertical presentation mode was compared to a simultaneous, but horizontal presentation mode. We hypothesized a strongest compatibility effect with the vertical as opposed to the horizontal presentation mode. For purposes of validation we also compared both presentation modes to a consecutive presentation mode with numbers being presented after each other.

Table 1. Item characteristics for compatible and incompatible items in each condition ($M \pm SD$)

	Vertical/close		Horizontal/distant		Consecutive	
	Compatible	Incompatible	Compatible	Incompatible	Compatible	Incompatible
Larger number	75.80 \pm 15.83	75.45 \pm 14.44	75.83 \pm 17.29	75.43 \pm 15.17	76.20 \pm 16.01	75.73 \pm 15.78
Smaller number	42.38 \pm 15.49	42.53 \pm 14.28	42.25 \pm 16.54	42.60 \pm 14.38	42.50 \pm 16.06	42.68 \pm 15.07
First number	58.83 \pm 23.06	59.03 \pm 22.73	58.95 \pm 23.95	58.90 \pm 21.31	59.25 \pm 22.24	59.23 \pm 21.07
Second number	59.35 \pm 23.05	58.95 \pm 21.25	59.13 \pm 24.02	59.13 \pm 23.14	59.45 \pm 24.53	59.18 \pm 24.34
Distance	33.43 \pm 16.00	32.93 \pm 17.01	33.58 \pm 15.81	32.83 \pm 16.89	33.70 \pm 15.91	33.05 \pm 17.16
Decade distance	2.80 \pm 1.64	3.83 \pm 1.69	2.83 \pm 1.62	3.80 \pm 1.68	2.85 \pm 1.64	3.83 \pm 1.72
Unit distance	5.43 \pm 1.38	5.33 \pm 1.31	5.33 \pm 1.27	3.18 \pm 1.11	5.20 \pm 1.20	5.20 \pm 1.24

We expected to replicate previous findings that with a moderate amount of within-decade items, a unit-decade compatibility effect occurs only with simultaneous presentation, but not with consecutive presentation.

In the second study, number comparison stimuli were presented simultaneously, vertically above each other on the screen, but either spaced closely or spaced farther apart, similar to the spacing of local elements in hierarchical stimuli. We hypothesized a stronger compatibility effect with closer presentation modes than with more distant spacing.

Methods

Participants

Thirty-two healthy men (mean age: 23.60 \pm 4.29 years, range: 19–40 years) participated in Study 1 and 32 healthy men (mean age: 25.65 \pm 2.77 years, range: 20–30 years) in Study 2. Participants of both studies were right-handed, had no psychological or neurological disorder according to self-reports, and were not currently on medication. All subjects gave their informed written consent to participate in the study. The experiments were conducted in accordance with the Declaration of Helsinki.

Stimuli

In both studies, participants completed a number comparison task with different presentation modes. Participants were presented with 2 two-digit numbers and had to decide, which number was larger. Although the instruction to identify the larger *number* refers to the global level (number magnitudes not digit magnitudes) it is not explicitly stated, which level to attend. Participants are free to solve the task on the global level, by comparing the magnitudes of the whole numbers, or on the local level, by comparing the magnitudes of the digits.

For each presentation mode in each study, 100 items were presented. Forty items were unit-decade compatible (C), that is, the smaller number contained the smaller unit

digit (e.g., 67_43), and 40 were unit-decade incompatible (I), that is, the smaller number contained the larger unit digit (e.g., 63_47). Furthermore, 20 within-decade items, that is, items where the two numbers contained the same decade digit (e.g., 63_67), were included. Within-decade items prevent a strategy of only comparing decade digits, as they require the processing of unit digits.

Problem size (size of larger and smaller number), absolute distance, decade distance (the absolute distance between the decade digits of the two numbers), unit distance (the absolute distance between the unit digits of the two numbers), and parity were matched across presentation modes; problem size and absolute distance were furthermore matched between compatible and incompatible items (Table 1). In each condition (Presentation Mode \times Compatibility), half of the items had small decade distance (1–4), the other half large decade distance (> 4). All items had large unit distance (> 4). Numbers ranged from 21 to 98. Except for within-decade items, all four digits of an item were different. All items were presented for 2 s, preceded by a 1 s fixation period.

Study 1

The 2 two-digit numbers were presented blockwise in three different presentation modes.

- (i) Vertically above each other in the middle of the screen (Figure 1A).
- (ii) Horizontally next to each other in the middle of the screen (Figure 1B). The vertical and horizontal distance between the numbers extended a visual angle of 11.5°.
- (iii) Consecutively, that is, the first number appeared at the center of the screen for 1 s, disappeared and was followed by the second number appearing on the screen for 1 s (Figure 1C).

Study 2

The 2 two-digit numbers were displayed above each other in the middle of the screen (Figure 1D). In half of the items, the two numbers were presented close to each other, extending a visual angle of 11.5°. In the other half of the

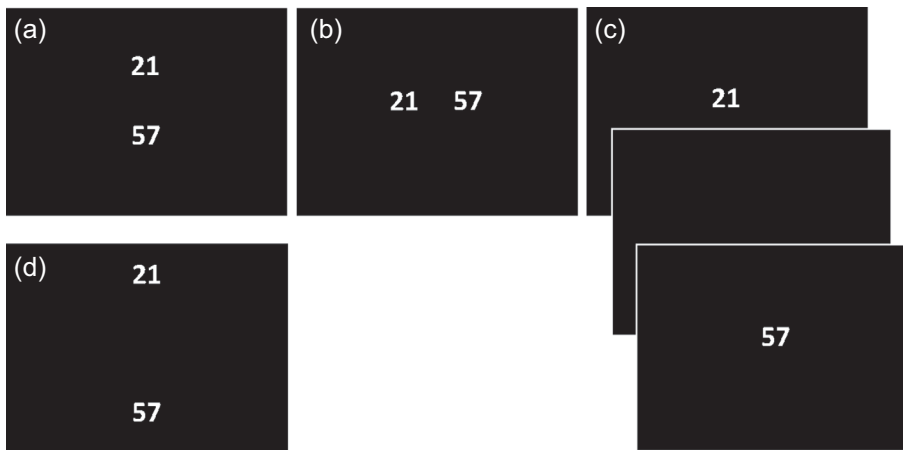


Figure 1. Example stimuli for each presentation mode. (A) vertical, (B) horizontal, (C) consecutive, (D) distant spacing.

items, the two numbers were presented distant to each other, extending a visual angle of 22° . Presentation modes were randomized. In half of the items of each condition, the upper number was larger, in the other half, the lower number was larger.

Analyses

Statistical analysis was carried out using software JASP 0.7.5.5 (<https://jasp-stats.org>). The impact of vertical spacing and presentation modes (vertical vs. horizontal; simultaneous vs. consecutive) on the compatibility effect in number comparison were assessed with 2×2 ANOVAs over the samples of the respective studies, which are described in more detail in the Results section. For nonsignificant effects Bayes Factors in favor of the null hypothesis (BF_{01}) were calculated. Data are available as electronic supplementary materials ESM 1 (Study 1) and ESM 2 (Study 2).

Results

Effects of Horizontal versus Vertical Presentation Mode on the Compatibility Effect (Study 1)

In order to determine the effect of horizontal versus vertical as presentation mode on the compatibility effect, a 2×2 ANOVA was run with “compatibility” (compatible vs. incompatible) and “presentation mode” (horizontal vs. vertical) as within-subject factors on both RT and ER (Error Rate).

Reaction Times

Large and significant main effects of both compatibility, $F(1, 31) = 35.61$, $MSE = 3,059.27$, $p < .001$, $\eta_p^2 = .54$, and

presentation mode, $F(1, 31) = 10.62$, $MSE = 2,637.75$, $p = .003$, $\eta_p^2 = .26$, were observed. Responses were slower to incompatible as compared to compatible trials and to vertically spaced as opposed to horizontally spaced trials. However, no significant interaction between Compatibility \times Presentation Mode, $F(1, 31) = 0.18$, $MSE = 1,973.41$, $p = .68$, $\eta_p^2 = .006$, was observed. A BF_{01} of 4.60 suggests anecdotal evidence for the null hypothesis, that is, that the compatibility effect was of equal size for vertical and horizontal presentation (Figure 2A).

Error Rates

A large and significant main effect of compatibility, $F(1, 31) = 24.89$, $MSE = 40.81$, $p < .001$, $\eta_p^2 = 0.45$, was observed. Participants made more errors on incompatible as compared to compatible items. However, no significant main effect of presentation mode, $F(1, 31) = 0.86$, $MSE = 16.28$, $p = .36$, $\eta_p^2 = 0.03$, was observed on error rates and no significant interaction between Compatibility \times Presentation Mode, $F(1, 31) = 0.54$, $MSE = 25.96$, $p = .47$, $\eta_p^2 = 0.02$. For the main effect of presentation mode, a BF_{01} of 5.20 suggests anecdotal evidence for the null hypothesis, that is, participants made a comparable amount of errors with the vertical and horizontal presentation. For the interaction between Compatibility \times Presentation Mode, a BF_{01} of 4.62 suggests anecdotal evidence for the null hypothesis, that is, that the compatibility effect was of comparable size with the vertical and horizontal presentation (Figure 2B).

Effects of Simultaneous Versus Consecutive Presentation on the Compatibility Effect (Study 1)

To determine the effect of simultaneous versus consecutive presentation on the compatibility effect, two separate 2×2

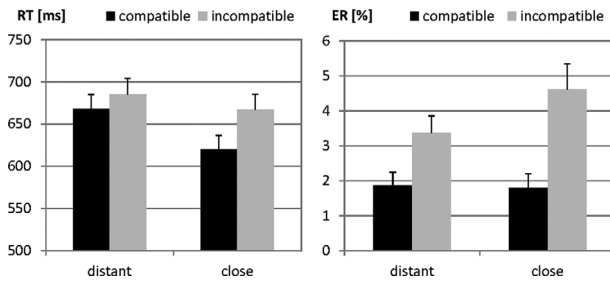


Figure 2. Effect of vertical spacing on the compatibility effect in number comparison (Study 1). The compatibility effect in RT was smaller, if the distance between numbers was larger. RT = reaction times; ER = error rates. Error bars represent standard errors.

ANOVAs were run with “compatibility” (compatible vs. incompatible) and “presentation mode” (simultaneous vs. consecutive) as within-subjects factors. For the simultaneous condition, once reactions to the horizontally and once reactions to the vertically presented numbers were used.

Reaction Times

For both comparisons, a large and significant effect of compatibility (vertical: $F(1, 31) = 6.38$, $MSE = 1,861.09$, $p < .01$, $\eta_p^2 = 0.17$; horizontal: $F(1, 31) = 4.81$, $MSE = 3,425.02$, $p < .05$, $\eta_p^2 = 0.13$), as well as a significant effect of presentation mode (vertical: $F(1, 31) = 10.85$, $MSE = 36,145.11$, $p = .001$, $\eta_p^2 = 0.26$; horizontal: $F(1, 31) = 5.89$, $MSE = 35,730.02$, $p < .05$, $\eta_p^2 = 0.16$) were observed. Responses were slower for incompatible compared to compatible as well as for simultaneous versus consecutive presentation. Furthermore, for both comparisons, a highly significant interaction of Compatibility \times Presentation Mode (vertical: $F(1, 31) = 13.61$, $MSE = 2,992.24$, $p = .001$, $\eta_p^2 = 0.31$; horizontal: $F(1, 31) = 35.05$, $MSE = 1,393.97$, $p < .001$, $\eta_p^2 = 0.53$) was observed. No significant compatibility effect was observed, when numbers were presented consecutively (Figure 2A). However, a BF_{01} of 2.82 fails to provide evidence for the null hypothesis of no compatibility effect with consecutive presentation.

Error Rates

For both comparisons, large and significant main effects of both compatibility (vertical: $F(1, 31) = 10.87$, $MSE = 23.36$, $p = .002$, $\eta_p^2 = 0.26$; horizontal: $F(1, 31) = 10.37$, $MSE = 37.40$, $p = .003$, $\eta_p^2 = 0.25$), as well as presentation mode (vertical: $F(1, 31) = 11.39$, $MSE = 59.04$, $p = .002$, $\eta_p^2 = 0.27$, horizontal: $F(1, 31) = 6.09$, $MSE = 80.79$, $p < .05$, $\eta_p^2 = 0.16$) were observed. Participants made more errors on incompatible as compared to compatible trials and when numbers were presented consecutively, as when numbers were presented simultaneously. Furthermore, a large and significant interaction was observed between Compatibility \times Presentation Mode (vertical: $F(1, 31) = 5.16$,

$MSE = 28.77$, $p = .03$, $\eta_p^2 = 0.14$; horizontal: $F(1, 31) = 9.21$, $MSE = 27.59$, $p < .05$, $\eta_p^2 = 0.23$). The compatibility effect in error rates was larger, when numbers were presented simultaneously, than when they were presented consecutively (Figure 2B). No significant compatibility effect was observed, when numbers were presented consecutively, $F(1, 31) = 3.16$, $p = .08$. A BF_{01} of 4.42 provides anecdotic evidence for the null hypothesis of no compatibility effect with consecutive presentation.

Effects of Vertical Spacing on the Compatibility Effect (Study 2)

To determine the impact of vertical spacing on the compatibility effect, a 2×2 ANOVA was run with the within-subjects factors, compatibility (compatible vs. incompatible), and, vertical spacing (close vs. distant) on both reaction times (RT) and error rates (ER).

Reaction Times

Large and significant main effects of both compatibility, $F(1, 31) = 26.98$, $MSE = 2,443.70$, $p < .001$, $\eta_p^2 = 0.47$, and vertical spacing, $F(1, 31) = 42.73$, $MSE = 1,610.78$, $p < .001$, $\eta_p^2 = 0.58$, were observed. Responses were slower for incompatible compared to compatible items and for large vertical spacing compared to small vertical spacing. Furthermore, a large and significant interaction effect of Compatibility \times Vertical Spacing was observed, $F(1, 31) = 13.53$, $MSE = 1,044.63$, $p = .001$, $\eta_p^2 = 0.30$. The compatibility effect was larger with close spacing compared to distant spacing (Figure 3A). However, the compatibility effect was still significant with the more distant spacing, $F(1, 31) = 6.19$, $MSE = 1,536.64$, $p < .05$, $\eta_p^2 = 0.17$.

Error Rates

A large and significant main effect of compatibility, $F(1, 31) = 14.47$, $MSE = 20.41$, $p = .001$, $\eta_p^2 = 0.32$, was observed. Participants made significantly more errors on incompatible trials as compared to compatible trials. However, no significant main effect of vertical spacing on error rates, $F(1, 31) = 1.54$, $MSE = 14.31$, $p = .23$, $\eta_p^2 = 0.05$, was observed and only a trend for a Compatibility \times Vertical Spacing interaction was observed, $F(1, 31) = 3.69$, $MSE = 7.66$, $p = .06$, $\eta_p^2 = 0.11$. For the main effect of presentation mode, a BF_{01} of 4.21 provides anecdotic evidence for the null hypothesis, that is, participants made a comparable amount of errors with close and distant spacing of the numbers. However, for the interaction of Compatibility \times Spacing, a BF_{01} of 2.31 fails to provide evidence for the null hypothesis, that the compatibility effect does not differ between close and distant spacing condition (Figure 3B).

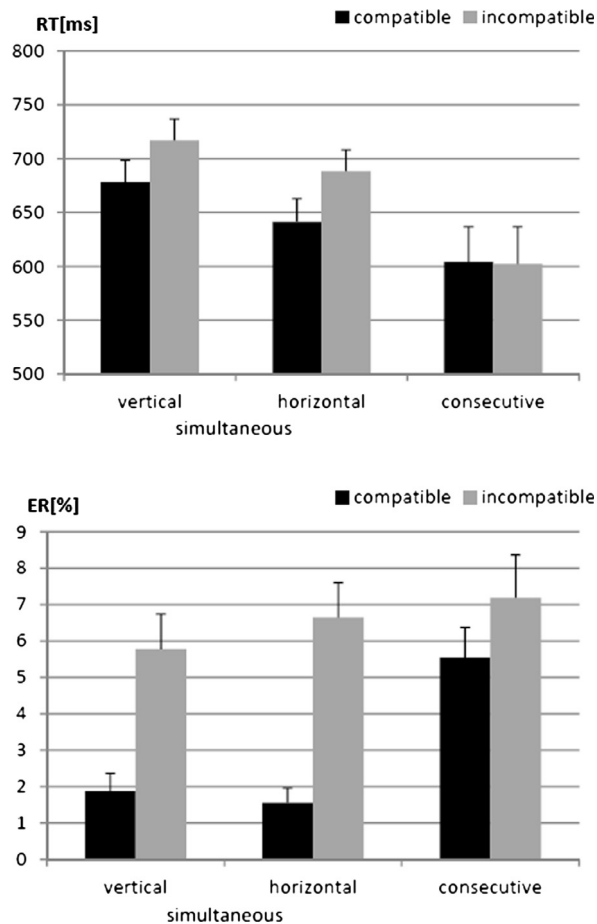


Figure 3. Effects of presentation mode (vertical vs. horizontal, simultaneous vs. consecutive) on the compatibility effect in number comparison (Study 2). There was no difference in the compatibility effect between vertical and horizontal simultaneous presentation, but the compatibility effect disappeared with consecutive presentation. RT = reaction times; ER = error rates. Error bars represent standard errors.

Discussion

The present studies were designed to assess the effects of different presentation modes on the compatibility effect during number comparison in men. According to Bayesian analyses, the compatibility effect was of comparable size between the horizontal and the traditional vertical presentation format. However, the compatibility effect was significantly smaller with the consecutive presentation format than with both simultaneous presentation formats. Furthermore, we found that as expected, the compatibility effect was larger, if numbers were spaced closer together than when spaced further apart.

The fact that simultaneous presentation leads to a comparable compatibility effect, irrespective of whether numbers are presented vertically, horizontally (this study), or diagonally (Nuerk et al., 2004), provides support for

decomposed processing of number magnitudes. The compatibility effect is not enhanced if presented vertically in a mode which is taught for digitwise addition and subtraction in school. However – as demonstrated previously (Ganor-Stern et al., 2009; Zhou et al., 2008) the compatibility effect is nonsignificant with consecutive presentation of numbers, which compares to a large number of studies using fixed standards for number comparison that did not find a compatibility effect. This suggests that with consecutive presentation, the whole number magnitudes are processed before comparison. However, Bayesian analyses did not allow the conclusion of a null effect of compatibility with the consecutive presentation mode. This compares to recent results of Moeller et al. (2013), that a compatibility effect can be elicited with consecutive presentation if a large number of within-decade trials is used.

The effect of vertical spacing shows strong similarities to previous effects of stimulus spacing on mathematical processes (Landy & Goldstone, 2007a, 2007b, 2010). If numbers are spaced closely together, it is more likely that the magnitudes of their constituting digits are compared before the magnitudes of the whole numbers. The close spacing furthermore supports parallel comparison of decade and unit magnitudes as reported by Moeller et al. (2009), since all digits can be viewed at once. If numbers are spaced further apart, two scenarios are possible. Either, the whole numbers are processed before comparison or participants resort to a more sequential, but decomposed comparison, since the distant spacing prevents parallel comparison of decades and units. While the present study design does not allow a definite decision on which processing mode was used by participants, both, theoretical considerations, as well as individual subject data rather support the assumption of holistic than sequential processing. First, with the distant spacing, the two digits of one number are much more close together than the decade or unit digits of the different numbers. Based on the results of Landy and Goldstone (2010), more narrow spaced problems tend to be solved first, suggesting that in the distant spacing condition participants would more likely first process the whole number magnitude of one number before comparing it to the second number. Second, sequential comparison should elicit a reversed compatibility effect. However, the compatibility effect is still significant in the original direction in the distant spacing condition. When analyzing compatibility effects over items for each participant individually, only 13 participants show a negative compatibility effect in the distant spacing condition, 11 of which are of small effect size. For participants with a positive compatibility effect, effect sizes are on average in the medium range.

In summary, we found no effect of presentation mode on the compatibility effect as long as numbers are presented simultaneously on the screen, but the compatibility effect

is influenced by the distance between the numbers, such that more distant spacing results in a smaller compatibility effect. Together, these results suggest that presentation mode and spacing can change the processing mode for multi-digit numbers (e.g., from decomposed to holistic or from parallel to sequential). Thus, information on number size and distance between numbers should be reported in studies on the unit-decade compatibility effect.

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Electronic Supplementary Materials

The electronic supplementary material is available with the online version of the article at <http://dx.doi.org/10.1027/1618-3169/a000326>

ESM 1. Raw data (sav).

Raw data for Study 1.

ESM 2. Raw data (sav).

Raw data for Study 1.

References

- Brybaert, M. (1995). Arabic number reading: On the nature of the numerical scale and the origin of phonological recoding. *Journal of Experimental Psychology: General*, 124, 434–452. doi: 10.1037/0096-3445.124.4.434
- Dehaene, S., Dupoux, E., & Mehler, J. (1990). Is numerical comparison digital? Analogical and symbolic effects in two-digit number comparison. *Journal of Experimental Psychology: Human Perception and Performance*, 16, 626–641. doi: 10.1037/0096-1523.16.3.626
- Ganor-Stern, D., Pinhas, M., & Tzelgov, J. (2009). Comparing two-digit numbers: The importance of being presented together. *The Quarterly Journal of Experimental Psychology*, 62, 444–452. doi: 10.1080/17470210802391631
- Jiang, M. J., Cooper, J. L., & Alibali, M. W. (2014). Spatial factors influence arithmetic performance: The case of the minus sign. *The Quarterly Journal of Experimental Psychology*, 67, 1626–1642.
- Kirshner, D. (1989). The visual syntax of algebra. *Journal of Research in Mathematics Education*, 20, 274–287.
- Kramer, J. H., Ellenberg, L., Leonhard, J., & Share, L. J. (1996). Developmental sex differences in global-local perceptual bias. *Neuropsychology*, 10, 402–407. doi: 10.1037/0894-4105.10.3.402
- Landy, D., & Goldstone, R. L. (2007a). How abstract is symbolic thought? *Journal of Experimental Psychology: Learning, Memory & Cognition*, 33, 720–733.
- Landy, D., & Goldstone, R. L. (2007b). Formal notations are diagrams: Evidence from a production task. *Memory & Cognition*, 35, 2033–2040.
- Landy, D., & Goldstone, R. L. (2010). Proximity and precedence in arithmetic. *The Quarterly Journal of Experimental Psychology*, 63, 1953–1968.
- Martin, M. (1979). Local and global processing – Role of sparsity. *Memory & Cognition*, 7, 476–484. doi: 10.3758/BF03198264
- Moeller, K., Fischer, M. H., Nuerk, H.-C., & Willmes, K. (2009). Sequential or parallel decomposed processing of two-digit numbers? Evidence from eye-tracking. *The Quarterly Journal of Experimental Psychology*, 62, 323–334. doi: 10.1080/17470210801946740
- Moeller, K., Klein, E., Nuerk, H.-C., & Willmes, K. (2013). Magnitude representation in sequential comparison of two-digit numbers is not holistic either. *Cognitive Processing*, 14, 51–62. doi: 10.1007/s10339-012-0535-z
- Navon, D., & Norman, J. (1983). Does global precedence reality depend on visual angle? *Journal of Experimental Psychology: Human Perception and Performance*, 9, 955–965. doi: 10.1037/0096-1523.9.6.955
- Nuerk, H.-C., Weger, U., & Willmes, K. (2001). Decade breaks in the mental number line? Putting the tens and units back in different bins. *Cognition*, 82, B25–B33. doi: 10.1016/S0010-0277(01)00142-1
- Nuerk, H.-C., Weger, U., & Willmes, K. (2004). On the perceptual generality of the unit-decade-compatibility effect. *Experimental Psychology*, 51, 72–79. doi: 10.1027/1618-3169.51.1.72
- Pletzer, B., Kronbichler, M., Nuerk, H.-C., & Kerschbaum, H. (2013). Sex differences in the processing of global vs. local stimulus aspects in a two-digit number comparison task – An fMRI study. *PLoS One*, 8, e53824. doi: 10.1371/journal.pone.0053824
- Pletzer, B., Petasis, O., & Cahill, L. (2014). Switching between forest and trees: Opposite relationship of progesterone and testosterone to global-local processing. *Hormones and Behavior*, 66, 257–266. doi: 10.1016/j.yhbeh.2014.05.004
- Poltrock, S. E., & Schwartz, D. R. (1983). Comparative judgments of multidigit numbers. *Journal of Experimental Psychology Learning Memory and Cognition*, 10, 32–45.
- Razumnikova, O. M., & Vol'f, N. V. (2011). Selection of visual hierarchical stimuli between global and local aspects in men and women. *Human Physiology*, 38, 33–42. doi: 10.1134/S0362119712040111
- Roalf, D., Lowery, N., & Turetsky, B. I. (2006). Behavioral and physiological findings of gender differences in global-local visual processing. *Brain and Cognition*, 60, 32–42. doi: 10.1016/j.bandc.2005.09.008
- Verguts, T., & De Moor, W. (2005). Two-digit comparison decomposed, holistic or hybrid? *Experimental Psychology*, 52, 195–200. doi: 10.1027/1618-3169.52.3.195
- Zhou, X., Chen, C., Chen, L., & Dong, Q. (2008). Holistic or compositional representation of two-digit numbers? Evidence from the distance, magnitude, and SNARC effects in a number-matching task. *Cognition*, 106, 1525–1536. doi: 10.1016/j.cognition.2007.06.003

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