Supplemental material: Interference between number magnitude and parity: Discrete representation in number processing

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The relation of the unified and the dual interference indices

How are the two interference calculation methods related, and what information are they sensitive to? In the classic method (Fias, Brysbaert, Geypens, & d'Ydewalle, 1996; Lorch & Myers, 1990) a single index is calculated for the interference (that is why we term it *unified index*), and its deviation from zero is tested, while in the new method two indices are calculated (that is why we term it *dual index*), and their correlation is tested.

What is the relation between the unified index and the dual index? In the following explanation we use the example of the SNARC effect, but the reasoning can be extended to other interference, too. Figure 1 shows an example data that both unified and dual indices rely on. Median reaction time for all numbers for both hands are calculated, (top lines of Figure 1), then reaction time difference between the two hands are computed (bottom line of Figure 1). Linear regression can specify the slope of the reaction time change across numbers for both hands and the hand differences. The unified index uses the slope of the hand differences (bottom line on Figure 1), while the dual index uses the left- and right-hand slope pairs (top lines on Figure 1).

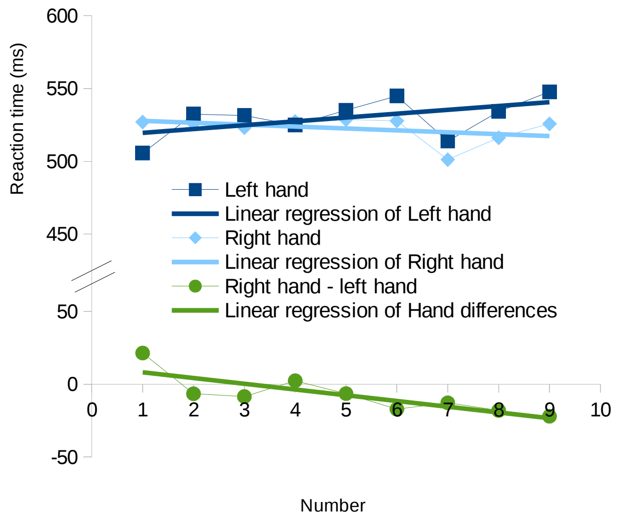


Figure 1 Components of the indices in a SNARC effect in the example of the present data. Median reaction time for both hands (top solid lines) and hand differences (bottom dashed line) for all numbers, and the three linear regressions. Slope of the top solid regression lines form the dual index, slope of the bottom dashed regression line forms the unified index.

The two components of the dual index (slopes of the left- and right-hand regressions) can be displayed on a scatterplot (as seen on Figure 4 in the main text and Figure 2). How can the unified index be related to these points? The unified index is the difference of the two components of the dual index, thus displaying the unified index on this scatterplot is the distance from the y = x line. One can also imagine a new axis along the y = -x line on the scatterplot, and the projections of the dots onto this new axis will serve as the unified interference values (Figure 2).

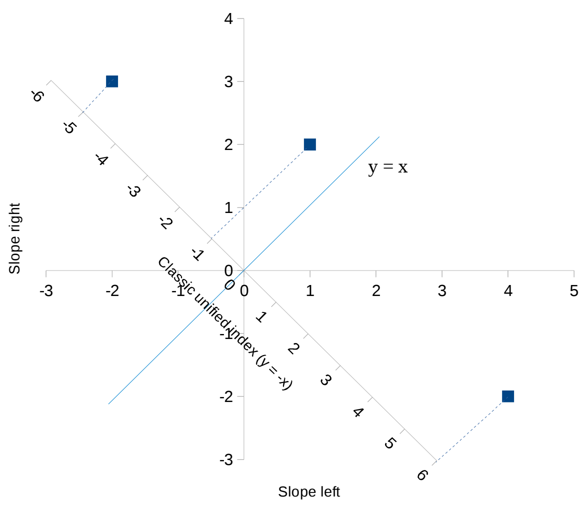


Figure 2 The relation of the dual index and the unified index. Point coordinates represent the left- and right-hand slopes (the dual index), while the projection of the dots to the y = -x line represent the unified index.

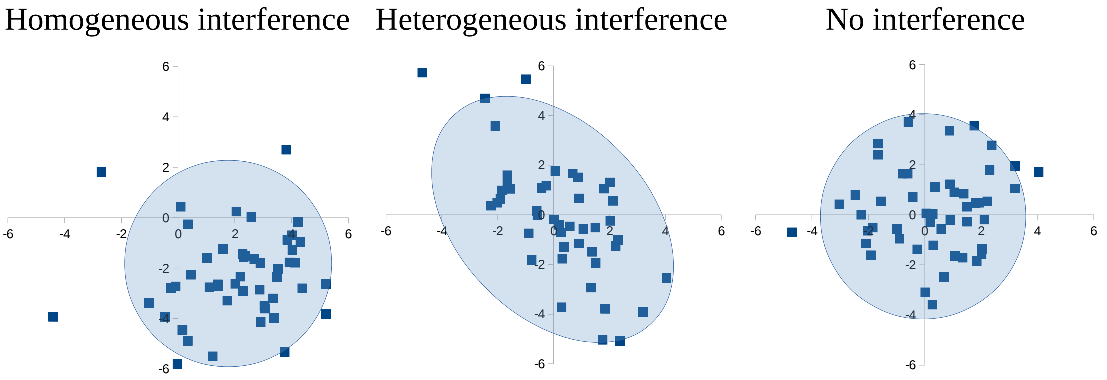
What information are the unified and the dual indices sensitive to? The unified index can unveil an interference only if the direction of the interference is homogeneous in the group (i.e., all or most participants show the same direction of the associated properties), while the dual index can reveal an interference when the direction of the interference is heterogeneous (i.e., the direction of the association is mixed across participants).

To explore how the two indices can be sensitive to different types of interference effects, homogeneous, heterogeneous and missing interference effects are shown on Figure 3. (a) In a homogeneous interference the association is unidirectional, e.g., large numbers are associated with the right response side, resulting in positive slope for left hand and negative slope for the right hand, thus, most participants are in a single quadrant of the plot. (b) In a heterogeneous interference some participants are in one quadrant of the plot, while other participants are in the opposite quadrant of the plot (e.g., depending on the direction of the reading some associate large numbers with left side and some others associate large numbers with right side), while the remaining two quadrants are not populated. (c) When there is no interference, the slopes can take any values, reflecting only random noise (these are from the current viewpoint irrelevant individual differences and measurement noise), and any quadrants of the plot could be used. How efficient can the two indices be in these cases? (1) The unified index can unveil the homogeneous interference, because the data of the participants dominantly lie on one side of the y = x curve. However, because heterogeneous interference is indistinguishable from the lack of interference in the unified values (in both cases data are evenly on the two sides of the y = x curve), unified index cannot reveal heterogeneous interference.[1] (2) On the other hand, the dual index shows a strong negative correlation in a heterogeneous interference, because the two slopes (components of the index) move in the opposing directions, placing the data into two opposing quadrants of the scatterplot.[2] When there is no interference, the dual index does not show any correlation. In homogeneous correlation it is possible that the strength of the interference effect (the slopes) show individual differences, resulting in a negative correlation in the dual index. However, the variance of the individual difference would be much smaller than in the case of the heterogeneous variance in which case the direction (sign of the slope) change caused higher variance. Thus, in homogeneous interference we can expect some

1 One might suggest that the unified index can detect heterogeneous interference, because the index would show bimodal distribution. The main problem is that bimodal distribution is not guaranteed, and it could be considered convincing only under specific circumstances. In fact, bimodal distribution could be demonstrated if (a) we suppose that the effect size (slope) cannot take any values in the group, i.e., in both association direction subgroups the effect size is around a relatively fixed value, and (b) if the standard deviations of the two association direction subgroups are not too high compared to the effect sizes (i.e., the two distributions do not overlap considerably). Moreover, if a subgroup without interference is present, it would make the distribution trimodal, which would make the two interference subgroups even less visible. Violating these conditions would seriously decrease the possibility that bimodality (or trimodality if a no-interference subgroup is supposed) can be revealed without an unreasonably high sample size.

2 In some simple cases in a heterogeneous interference the data reside in the top left and bottom right quadrants of the scatterplot, although this is not a necessary feature of heterogeneous interference effects. E.g., one can imagine that for some reasons the response for the number 9 is extremely slow independent of the hands, raising the slopes of both left hand and the right hand (as if the reaction time in Figure 1 were even higher). This change in the slopes causes a shift of the data to the top right direction in the scatterplot, potentially moving most of the data to the top right quadrant (as if the dots are moving to the top right quadrant in middle plot of Figure 3). In this case, the sample is still heterogeneous, and the correlation is still negative, however, the data are not in the original two quadrants of the scatterplot.

correlation in the dual index, however, it should be much smaller than the correlation in the heterogeneous interference.



Unified index	Deviates from zero	Does not deviate from zero	Does not deviate from zero
Dual index	Potentially slight negative correlation	Strong negative correlation	No correlation

Figure 3 Functioning of the two indices in heterogeneous interference, in homogeneous interference, and with no interference (hypothetical data)

The examples above (Figure 3) are the clear cases, when (a) the interference is completely homogeneous, i.e., all participants show the same direction of association, or when (b) the interference is completely heterogeneous, i.e., half of the participants shows one direction of association, and the other half shows the other direction, or when (c) the interference is completely missing. However, there could be mixed cases of interference effects. First, it is possible that some participants show no interference in an otherwise interfering group, resulting in lower homogeneous/heterogeneous interference on the group level. Second, homogeneous and heterogeneous interference effects might get mixed, in which case the proportion of the participants with different directions of association would not be 50-50% (heterogeneous interference) or 100%-0% (homogeneous interference), but values in between, e.g., 30-70%. In the latter case we expect that both the unified index deviates from zero, and the dual index correlates, although the effect sizes should be smaller than in the case of pure homogeneous/heterogeneous interference effects.

This description might also shed new light upon the analysis of the seminal work of Dehaene et al. (1993), and it can explain why the present method is more appropriate to detect heterogeneous interference. In that study, in a first approach using the unified index, the SNARC effect was not observed in Iranian participants living in France. However, the unified SNARC index and the time spent in France correlated: participants who moved to France recently showed the Iranian association (large is on the left), while participants living in France for a longer time showed the Western association (large is on the right). In our terminology this interference is heterogeneous (Figure 4), because participants show both Iranian and Western number magnitude-space associations. But the unified index alone was insufficient to reveal the interference, nevertheless, time spent in France changed the association, and with the correlation of this variable and the

SNARC effect, the interference became visible. However, with the dual index the interference could be observable even without the need of the information about the time spent in France.

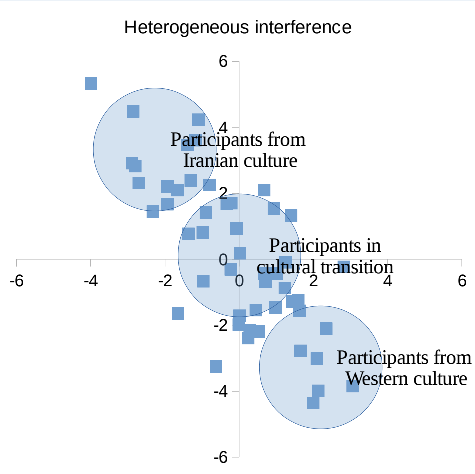


Figure 4 The influence of the Western and Iranian culture on the SNARC effect displayed with hypothetical data

To summarize, the two indices reveal two different types of interference: the unified index can efficiently show the homogeneous interference, while the dual index efficiently reveals heterogeneous interference. Previous studies mostly failed to unveil heterogeneous interference, because the unified index was insufficient to show them. Based on the reasoning above, it is recommended to use both indices while investigating any interference effects.

Results

Handedness

Interference effects calculated only with the right-handed participants showed exactly the same pattern as calculated with the whole sample (see also Figure 5). The PNARC index did not differ from zero with the unified index (mean slope = 1.23, 95% CI [-1.30, 3.76], $t(47) = 0.98$, $p = 0.334$), however, measured with the dual index, the two slopes show a negative correlation ($r(46) = -0.469$, $p < 0.001$), showing a heterogeneous PNARC effect. The SNARC effect was observable with the unified index (mean slope = -3.68, 95% CI [-2.07, -5.29], $t(47) = -4.61$, $p < 0.001$), but not with the dual index ($r(46) = -0.006$, $p = 0.965$), revealing a homogeneous SNARC effect. The MARC effect was not shown with the unified index (mean slope = 6.45, 95% CI [25.31, -12.40], $t(47) = 0.688$, $p = 0.495$), while it was significant with the dual index ($r(46) = -0.427$, $p = 0.002$), reflecting a heterogeneous MARC effect.

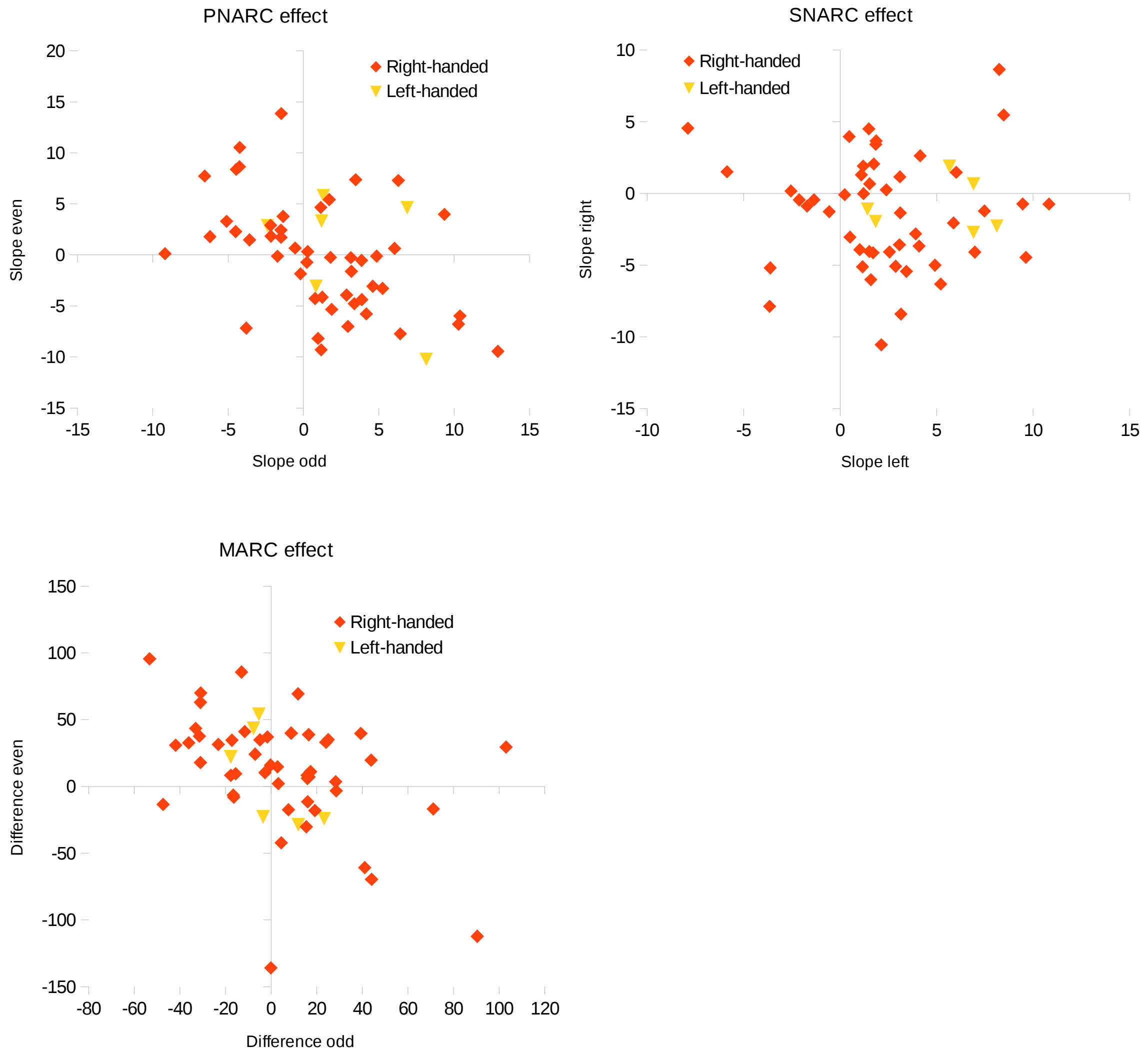


Figure 5 Scatterplot of (a) the slopes of even and odd numbers (PNARC), (b) the slopes of the right and left hands (SNARC), and (c) the hand differences of the even and odd numbers (MARC) as a function of right-handed and left-handed participants.

Replication

To ensure that these effects are not the result of type I errors, the reliability of these results were investigated. To check the reliability of the result, one of our previous study also including a parity decision task with the same methods as described above, was analyzed. In that study 29 university students participated in a parity decision task experiment. After excluding 3 of them, because they have more than 15% error rate, the data of 26 participants were analyzed, 5 of them were male, with a mean age of 22.8 years, standard deviation was 3.1 years. The PNARC was not significant with the unified index, mean slope = 3.19, 95% CI [-0.60, 6.99], $t(25) = 1.73$, $p = 0.095$, while it was significant with the dual index, $r(24) = -0.613$, $p < 0.001$. In these data the PNARC effect was also heterogeneous, as in our main study, and again we couldn't replicate the homogeneous PNARC effect found in Nuerk et al. (2004). The SNARC effect was not significant with the unified index, mean slope = -1.82, 95% CI [1.41, -3.77], $t(25) = -0.94$, $p = 0.356$, although a stronger outlier filtering made the effect significant (this was not true for the statistical tests of other effects reported here). The dual index did not show significant SNARC effect, r(24) = -0.329, p = 0.101. Overall, the SNARC effect tended to be homogeneous, while with this smaller sample size the result did not always reach significance. The MARC effect was not significant neither with the unified index, mean slope = 7.66, 95% CI [35.03, -19.71], t(25) = -0.576, p = 0.569, nor with the dual index, r(24) = -0.285, p = 0.158. In these data we could not replicate the heterogeneous MARC interference, showing the only difference between the main study and the preliminary study. This is in line with the difficult replicability of the MARC effect, discussed above. Most importantly the PNARC effect could be replicated, confirming the reliability of the effect.

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