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Singing Numbers... in Cognitive Space

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Abstract. We assessed the automaticity of spatial-numerical and spatial-musical associations with a dual-task paradigm. Participants performed magnitude and pitch comparisons on sung numbers with variable pitch. Concomitant tasks required retention of either colour or location information. Results suggest that spatial associations of both magnitude and pitch are resource-dependent and that the spatial association for pitch is more powerful than that for magnitude.

1 INTRODUCTION

When we make lateralized responses to sort stimuli into two categories (e.g., small or large numbers, low or high tones) we show a preferential association between left or low response keys and small numbers or low tones, and between right or high keys and large numbers or high tones. These two response biases are called Spatial-Numerical Association of Response Codes [SNARC, ref. 1] and Spatial-Musical Association of Response Codes [SMARC, ref. 2], respectively. Both findings suggest that we use spatial representations for problem solving. Initial results suggested that SNARC requires no cognitive resources as it emerges automatically even when number magnitude is task-irrelevant [3] but cultural differences and flexible results raised the possibility of a non-automatized SNARC strategy [4]. Supporting the latter, SMARC is stronger in trained musicians than novices [2], suggesting learned spatial associations. This argument assumes that SNARC and SMARC use similar processing mechanisms.

A diagnostic tool to help understand processing mechanisms in a given task is the dual-task paradigm: If task A performance deteriorates when performed together with task B then task A is not automatized. Different task combinations can reveal the underlying processes. This method recently showed that SNARC disappears under verbal load in parity judgment but under spatial load in magnitude comparison, suggesting that spatial codes can be either visuo-spatially or verbally mediated [5]. Here we apply the dual-task logic to investigate the relationship between SNARC and SMARC and whether these are automatized effects.

2 METHOD

16 musically untrained students (9F, 7M, mean age: 22 years, 3 left-handers, all native English) participated. They had no visual or hearing impairments. In the two main tasks (magnitude and pitch comparison tasks, MCT and PCT) stimuli consisted of 5 English number words (*two*, *three, four*, *five* and *six*) sung by 4 different professional singers (2M, 2F) at 5 equidistant pitches (*B2, E3, A3, D4* and *G4)*. In MCT participants decided whether a sung target number was smaller or larger than the preceding reference; in PCT they decided whether the target was lower or higher in pitch than the preceding reference. Number *four* sung in pitch *A3* (the central value on each dimension) served as fixed reference for both tasks. Responses were given by pressing the lower left *V* and upper right *U* keys on a QWERTY keyboard to capture both horizontal SNARC and vertical SMARC.

Participants fixated a cross which appeared centred on a laptop display. The reference stimulus (1000 ms) was played through headphones, immediately followed by the target (1000 ms). Responses were recorded in ms from target onset and followed by a 300 ms central fixation cross (for correct responses), exclamation mark (for errors) or question mark (for omissions).

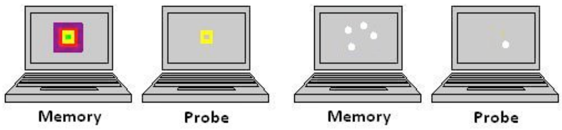

Figure 1. Sample memory and probe displays in the colour task (left, “yes” trial) and the location task (right side, “no” trial).

Two concomitant short-term memory tasks required maintenance of either colour or location information presented before each trial of the main task. In the *colour* task, squared concentric frames appeared centred on the screen; participants had to remember their colours. At the end of a trial, a single squared frame appeared and participants said aloud whether it had been present in the previous memory display (Fig. 1, left panels). In the *location* task, participants remembered the position of four dots appearing simultaneously on the screen at different positions of an imaginary central circle (each of them in a different quadrant). At the end of a trial, a single dot appeared at a position on the same imaginary central circle, and participants said whether it was part of the previous memory display (Fig. 1, right panels). The experimenter entered answers by clicking one of two mouse buttons. In either concomitant task, the memory stimulus remained visible for 150 ms, whereas the probe remained on screen until a response was entered.

The experiment was divided in two sessions to avoid fatigue, and completed on two different days. Each session comprised an initial training with either the colour and location tasks alone. Then baseline data were collected for one of the main tasks (single-task condition, first half), followed by the same task with both concomitant tasks, and finally by another baseline (single-task condition, second half). On each session a different main task was tested. Order of main and concomitant tasks was fully counterbalanced between participants, as were response rules.

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3 RESULTS

Main tasks were both performed with mean accuracy of 93% in the single-task condition, and 93% and 92% in the colour and location dual-task conditions, respectively. ANOVAs evaluated effects of *Task* (MCT, PCT), *Condition* (single-task, colour dual-task, location dual-task), *SMARC* (compatible, incompatible), and *SNARC* (compatible, incompatible) on correct RT and arcsine –transformed accuracy values. We report effects with $p < .05$.

Correct RT showed faster decisions in magnitude than pitch comparison. Single-tasks were performed faster than either dual-task. *SMARC* was reliable but *SNARC* was only marginal. Figure 2 shows a *Task* × *SMARC* × *SNARC* interaction.

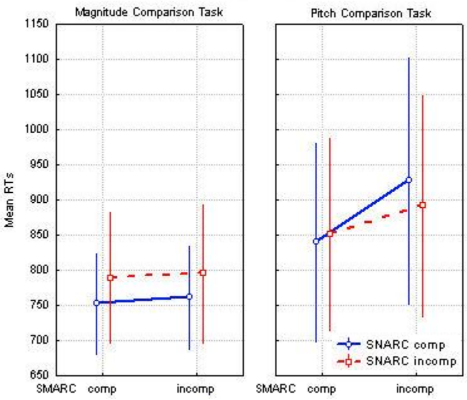

Figure 2. MCT showed a 35 ms SNARC but no SMARC. PCT showed a 63 ms SMARC but a 36 ms *reverse* SNARC in *SMARC* incompatible trials. Bars: 95% confidence intervals.

The accuracy analysis revealed main effects of *Task, SMARC* and *SNARC*. In MCT there was reliable *SNARC* without *SMARC*. In PCT there was reliable *SMARC* and a reverse *SNARC* in *SMARC* compatible trials, thus complementing RT results. Of interest for the present study, *Condition* revealed two interactions: First, *SNARC* was only reliable in the colour dual-task. Second, *SMARC* was not present during MCT but significant in both dual-task conditions during PCT (Figure 3).

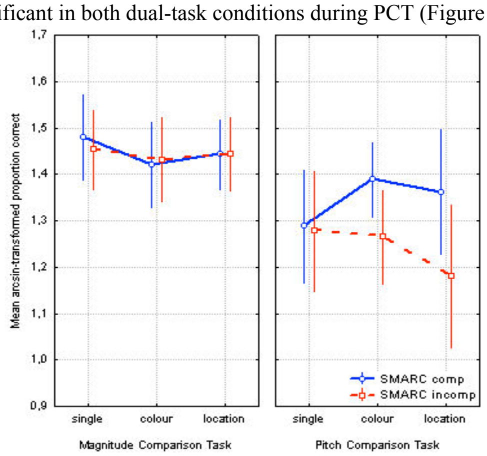

Figure 3. Relative to single task, SMARC suffered from dual-tasks in MCT whereas it improved in dual tasks during PCT.

4 DISCUSSION & FUTURE DEVELOPMENTS

Single tasks were easier than dual tasks (as required by the dual-task logic) and MCT was easier than PCT for our musically untrained participants. Both speed and accuracy data indicate that attending to magnitude induced SNARC without SMARC and attending to pitch induced SMARC without SNARC. This clear top-down modulation of both effects argues against automatic spatial associations of either stimulus dimension.

Only pitch but not numbers showed an *overall* spatial mapping in RT, and only SMARC was relatively immune to the different dual task demands (in terms of accuracy). This suggests that SMARC is overall stronger (more prevalent and consistent) than SNARC, which agrees with the considerable flexibility and cultural variability of SNARC effects [4].

The spatial memory task abolished SNARC in accuracy. This was not due to increased difficulty (which was comparable in the colour task) and suggests that both spatial mapping of numbers and memorizing locations use a common process. A candidate process is rapid successive deployment of spatial attention to all four probe locations to assign and maintain their coordinates during a trial [6]. Such attentional rehearsal would reduce resources available for associating numbers to spatial locations but would not be required to maintain verbal labels (colour names) in working memory.

This proposal might also account for the reversed SNARC while participants focused on pitch under incongruent SMARC mappings. For example, pressing a low button for a high pitch generated an incongruent spatial code (associating small height with large frequency) but also yielded faster responses for high magnitudes. Given the relevance of pitch, this result probably reflects the flexibility of mapping the irrelevant magnitude dimension of our compound stimuli: the assigned response coordinates linked high magnitude via high pitch.

The stronger SMARC under both dual task conditions might reflect the cost of incompatible more than the benefit of compatible SMARC mappings. Thus, even under load it remained easy to associate high pitch with high keys but it became harder to impose a reversal of this natural mapping.

Overall, this study documented resource-dependent spatial mapping of both magnitude and pitch. It suggests that the spatial mapping of pitch is more powerful than that of magnitude, consistent with its ontogenetically earlier acquisition and universal cultural occurrence. Future work should measure SNARC and SMARC throughout musical skill acquisition.

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