Review of Psychology,
2013, Vol. 20, No. 1-2, 47-51 UDC 159.9

A SNARC-like effect for music tempo

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The Spatial Numerical Association of Response Codes (SNARC) suggests the existence of an association between number magnitude and response position, with faster left-hand responses to small numbers and faster right-hand responses to large numbers (Dehaene, Bossini, & Giraux, 1993). Moreover, Rusconi, Kwan, Giordano, Umiltà, & Butterworth (2006) showed that the internal representation of pitch height is spatially organized, especially in participants with formal musical education (i.e., Spatial Musical Association of Response Codes: the SMARC effect). In the present study we investigated whether a similar association exists between music tempo (beats per minutes) and the spatial position of response execution. Participants were all musically untrained persons. To test our hypothesis they performed both an order-relevant task (i.e., time comparison task) and an order-irrelevant task (i.e., timbre judgment task). Results showed a global trend with faster left-hand responses to slower beat sequences and faster right-hand responses to faster beat sequences. From this evidences we can finally conclude that a SNARC-like effect exists for music tempo similar as for pitch height and numbers.

Key words: SNARC, music cognition, psychology of music, spatial response correspondence, tempo

Tempo is an essential component of any music production and, together with melody and harmony, it contributes to define the essence of a music piece. In music terminology, tempo represents the pace and speed of a music composition and it affects the mood and the difficulty of a piece. The typical measure unit for tempo is the BPM (beats per minute). Tempo can also be indicated with classical Italian tempo markings which goes from larghissimo (about 40 bpm or less) to prestissimo (about 200 bpm or more).

Many studies suggest that time and space are tightly coupled. It is possible that humans represent time as space and, in particular, the time flow can be represented using a spatial layout or a mental time line. The great majority of studies in the time domain show similarities with the space and number magnitude interaction. In fact the mental time line shares many features in common with the so-called mental number line (for a recent review see Bonato, Zorzi, & Umiltà, 2012).

Strong evidences of the space and numbers coupling was given by Dehaene, Bossini, and Giraux (1993) with the SNARC effect (i.e., Spatial Numerical Association of Response Codes). Dehaene et al. found that, if evaluating the number parity status was required, participants were faster at judging the parity of large numbers (e.g., 9) when responses were executed with the right effector (i.e., right hand key), whereas they were faster at judging the parity of smaller numbers (e.g., 1) when responses were executed with the left effector (i.e., left hand key). The SNARC effect suggests that relatively small numbers are spatially represented in the left hemispace and relatively large numbers are spatially represented in the right hemispace. These findings suggested the existence of a left-to-right oriented mental number line (i.e., MNL).

Some evidence for the existence of a SNARC-like effect in the music domain was given by Rusconi, Kwan, Giordano, Umiltà, and Butterworth (2006), who explored the spatial representation of pitch height using acoustic stimuli. The researchers observed a so-called SMARC effect (i.e., Spatial Musical Association of Response Codes) both when pitch height was task relevant (i.e., pitch comparison task) and when it was task irrelevant (i.e., *timbre judgment task*). Moreover, both musically trained and naïve partici-

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Acknowledgments: We thank Corinna Pannofino for improving the language form.

pants showed an association between "up" responses/high-pitched tones and "down" responses/low-pitched tones (i.e., vertical alignment) while only for musicians a consistent "right" responses/high-pitched tones and "left" responses/low-pitched tones association was observed (i.e., horizontal alignment). Naïve participants showed a trend toward the horizontal response association only in the task where pitch height processing was task relevant.

These findings were confirmed by Lidji, Kolinsky, Lochy, and Morais (2007), in a series of experiments aimed to investigate the spatial representation of both isolated tones (i.e., the same as Rusconi et al., 2006) and two-note melodic intervals. Results show that vertical alignment is probably the most natural representation for the pitch height of isolated tones. Indeed, this SNARC-like effect was observed for left-right association in naïve participants only in the pitch comparison task in which pitch processing was mandatory.

To explain the interaction between numbers, space, and time, Walsh (2003) proposed an innovative thesis called ATOM (i.e., A Theory Of Magnitude). According to the ATOM hypothesis, time and numbers are not actually represented in the space but, more generally, they share with space a common system for magnitude processing. As stated by Walsh, this system is designed to process all the magnitude dimensions classifiable as "more than-less than", "faster-slower", "nearer-farther", "bigger-smaller" (Bueti & Walsh, 2009). According to the authors, this analogue system is placed in the parietal cortex.

Another alternative explanation for the SNARC effect comes from Proctor and Cho (2006). The polarity correspondence theory argues that the association between left-hand advantage/small quantities and right-hand advantage/big quantities cannot be attributed to a certain representation with spatial characteristics. Otherwise, where binary responses are required, it can be attributed to a widespread tendency to polarize both the characteristics of stimuli and responses (Bonato et al., 2012).

Therefore, the aim of the present study was to investigate whether an association exists, in the overall population, between tempo and the side of response execution and whether this association has the properties of a left-to-right oriented mental line (i.e., Spatial Music Tempo Association of Response Codes: the SMTARC effect). Our hypothesis was we are going to find faster left hand responses with slower beat sequences and faster right hand responses with faster beat sequences. To test this, participants performed both an order-relevant task, the so called *time comparison task* (i.e., Experiment 1), and an order-irrelevant task, the so called timbre judgment task (i.e., Experiment 2). The first one allows us to investigate the spatial nature of the representation and the second one allows us to investigate the automaticity of the spatial codes activation.

METHOD

Experiment 1

Participants. Fourteen volunteers participated in the experiment, six males (mean age 25.3) and eight females (mean age 24.4). No one of the participants attended music conservatory or received formal musical education.

Apparatus and stimuli. The experiment was created and controlled by the E-Prime 2.0 software version. Stimuli consisted of 10 digital wave audio tracks, half with the classic metronome timbre sound and half with a synthesized beep timbre sound. Different timbre beat sequences were needed because the order-irrelevant task (i.e., Experiment 2) required the participants to evaluate the timbre of the stimuli. Both metronome and synthesized beep tracks had the same periodic rhythmical pattern and the same tempo. Probe beat sequences were 133 bpm, 150 bpm, 184 bpm, and 201 bpm, while the middle range stimuli (i.e., 167 bpm) was the reference beat sequence. Audio stimuli were presented through a couple of AKG professional hi-fi stereo studio headphones. Before starting the experiments, subjects were asked to choose a comfortable level of volume. The PC was an Intel Core i3 (RAM, 2 GB), with OS Windows 7. Responses were collected using a five button Serial Response Box connected to the PC with a serial port.

Procedure. All the participants were tested individually in a quiet room under the supervision of the experimenter. Participants were positioned in front of the PC and the midlines of the screen and the response box were aligned with the midline of the participant's body. They were instructed to move as little as possible. Participants were then asked to position their left index finger on the first key of the response box (i.e., the leftmost key) and their right index finger on the fifth key of the response box (i.e., the rightmost key).

A fixation cross was presented for 300 ms at the beginning of each trial, followed by an interstimulus interval (ISI) of 130 ms. Then the reference beat sequence (i.e., 167 bpm) was presented with a random duration of either 3500 or 5000 ms, followed by a 800 ms fixation cross and 130 ms ISI. After this the probe beat sequence was presented for 5000 ms and the participants were required to decide, within this time interval, if it was faster o slower than the reference stimuli. Responses were given by pressing button 1 or 5 of the response box and, as soon as the response was provided, the probe stimuli stopped and 1500 ms inter-trial interval (ITI) appeared before the whole sequence started again. Both speed and accuracy were stressed in the instructions.

The experiment was divided into two sessions. In the first one, participants were required to press the rightmost key (i.e., key number 5) with their right hand when the probe stimuli were faster than the reference beat sequence and the leftmost key (i.e., key number 1) with their left hand when the probe stimuli were slower than the reference beat sequence. Participants received the opposite assignment in the second session. Each session started with eight training trials and, then, each probe stimuli was presented 20 times in random order. Participants were allowed to take a short break between the two sessions if needed, otherwise they continued with the experiment. The sequence of presentation of each session was counterbalanced between participants.

Data analysis and results. Data analysis was carried out with the method of linear regression for repeated measures described by Fias, Brysbaert, Geypens, & d'Ydewalle (1996) and Lorch and Myers (1990). The independent variable was the probe beat sequences tempo, while the dependent variable was the difference between reaction time (RT) of the left hand and RT of the right hand: dRT = RT(right hand) - RT(left hand). Positive dRTs indicate faster responses with the left effector, whereas negative dRTs indicate faster responses with the right effector. A regression equation was computed for each participant with tempo as the predictor variable and, finally, one-sample t-tests were performed to verify whether regression's beta weights of the group deviated significantly from zero. The analysis of dRT revealed that regression slopes were significantly different from zero, $t(13) = -2.004$, $p < .05$ (see Figure 1). The results show a relative left effector advantage in processing slower beat sequences (i.e., 133 bpm and 150 bpm) and a relative right effector advantage for faster beat sequences (i.e., 184 bpm and 201 bpm).

Experiment 2

Participants, apparatus and stimuli were the same as those in Experiment 1.

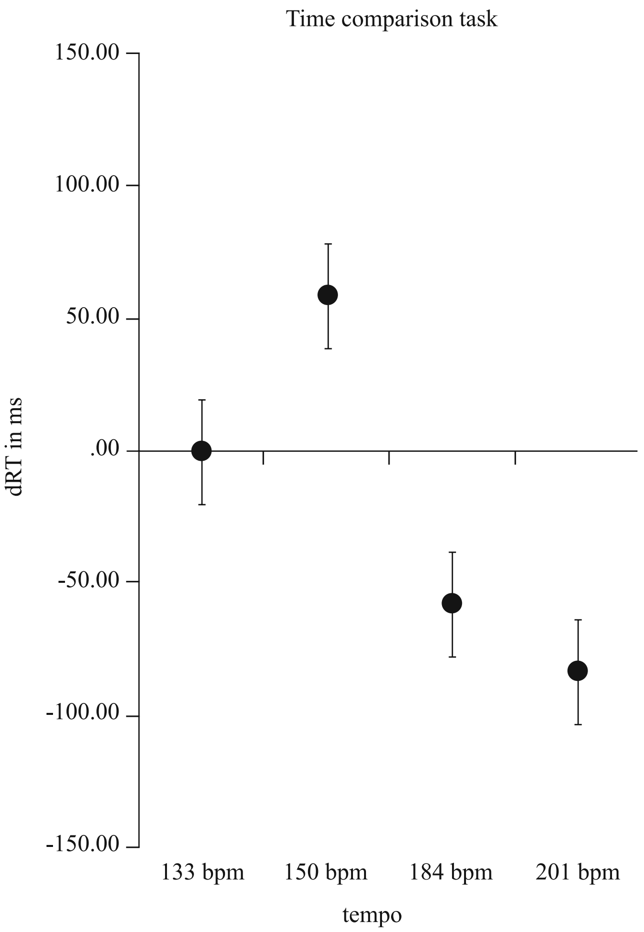

Figure 1. Mean differences (± 2 *SEM*) of the median reaction time (RT) right hand - median RT left hand, for the order-relevant task. Positive values indicate faster left hand responses; negative values indicate faster right hand responses. Error bars indicate 95% confidence intervals around mean dRT.

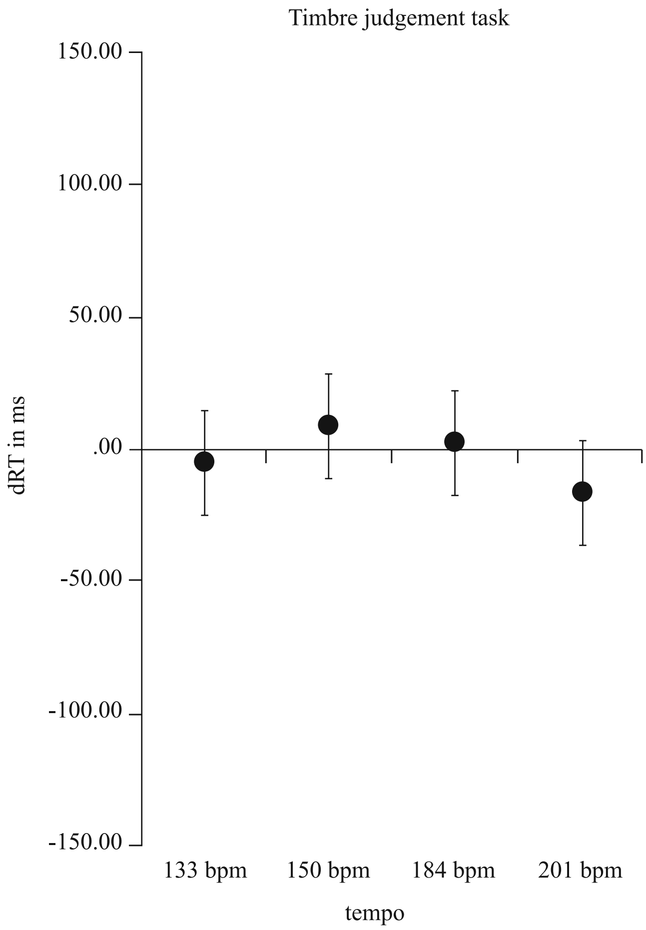

Figure 2. Mean differences (± 2 *SEM*) of the median reaction time (RT) right hand - median RT left hand for the order-irrelevant task. Positive values indicate faster left hand responses; negative values indicate faster right hand responses. Error bars indicate 95% confidence intervals around mean dRT.

Procedure. The procedure was similar to that described in the previous experiment. The main difference was that after the first interstimulus interval (ISI), only one audio stimulus was presented (i.e., one of the four probe tone sequences). Subsequently, 1500 ms ITI was presented and the whole sequence started again. Participants were asked to decide whether the timbre sound of the beat sequences were a classic metronome sound or a synthesized beep, by pressing button 1 or 5 of the response box. The experiment was divided into two sessions. In the first one participants were asked to press the rightmost key (i.e., button number 5) with their right hand when the timbre of the beat sequence was a metronome and the leftmost key (i.e., button number 1) with their left hand when the timbre of the beat sequence was a synthesized beep sound. The assignment was reversed in the second session and the order of the two sessions was counterbalanced between participants

Data analysis and results. Data analysis was the same as in Experiment 1. The analysis of dRT with tempo as predictor variable revealed that the regression slopes were not significantly different from zero, $t(13) = -.135$, *ns*. (Figure 2).

GENERAL DISCUSSION

We investigated whether there is an association between music tempo and the side of response execution and whether this association has the properties of a left-to-right oriented mental line (i.e., Spatial Music Tempo Association of Response Codes: the SMTARC effect). We expected to find faster left hand responses with slower beat sequences and faster right hand responses with faster beat sequences.

Our findings suggest the existence of a spatial association between music tempo and the space of response execution with the properties of a left-to-right oriented mental line. However, there is an undeniable deviation from this trend for the slowest tempo used. Furthermore, this association was found only when participants performed an order-relevant task (i.e., Experiment 1) while no association was found in the order-irrelevant task (i.e., Experiment 2). Similar data were found for the same variables (i.e., musically untrained participants, horizontal alignment) in the pitch height domain by Rusconi et al. (2005) and Lidji et al. (2007). The absence of association between left-hand/slower beats and right-hand/faster beats in Experiment 2 can be attributable to two explanations.

Perhaps the horizontal alignment is not the “natural” representation for tempo, in the same way as pitch height of isolated tones are more “intuitively” represented on the vertical axis (Lidji et al., 2007). Indeed, the SNARC-like association for pitch of single tones was found for the horizontal alignment only in the order-relevant task, in which pitch processing was mandatory, while a vertical response association was found for both order-relevant and order-irrelevant tasks. If this assumption is correct, an “up” responses/fast tempo and “down” responses/slow tempo association should be found for both time comparison and timbre judgment tasks. Additional evidence, used to predict the spatial representation of the stimuli in many SNARC and SNARC-like studies, is the existence of a spatial feature in common language expressions. For example, in the pitch domain, pitches are named as *high* or *low* suggesting a natural attitude for the vertical alignment. In a similar way, music tempo can be described using expressions as *high tempo/high bpm rates* or *low tempo/low bpm rates* suggesting a vertical “predilection” for tempo as well.

The second explanation could be the music expertise. As stated by Lidji et al. (2007), musicians are more prone to automatically process musical stimuli because of the high level of education and training. Indeed, this could be the explanation for the right effector/high pitched tones and left effector/low pitched tones associations found with musically trained participants even in an order-irrelevant task. In the same way, the absence of formal musical training in participants in our research could be the cause for the lack of response side association in the order-irrelevant task.

Present results can also be explained in the light of the polarity correspondence theory (Proctor & Cho, 2006) instead of the mental line metaphor proposed by Dehaene et al. (1993). According to Proctor and Cho, stimuli are categorized as small (-) or large (+) before the activation of a response side. In our case, stimuli are different tempo sequences and they should be coded as slow (-) or fast (+) compared to the reference stimulus. Results in the first experiment could be due to this task request, that is, task instructions indicate a bipolar code that induces “positive” and “negative” responses. Otherwise, the absence of a significant effect in the second experiment can be due to the lack of an automatic association between space and music tempo. If so, spatial association for tempo differs radically from those of numbers (Dehaene et al., 1993), and it can be shown only when tempo processing is mandatory.

Our findings lead us to think that the spatial response association for pitch and tempo are similar in many ways. An additional evidence for these similarities comes from a common result, found for both tempo and pitch (Lidji et al., 2007) in the order-relevant task performed by non musicians in the horizontal alignment. Concerning the pitch, Lidji et al. (2007) showed that the lowest of the low tones was less associated to the left key, whereas the highest of the high tones was, as expected, more associated to the right key than the lowest one was. This odd pattern was also found for tempo (Figure 1). No explanations can be found for this phenomenon at the moment but further investigations should focus on these unusual deviations, e.g., with the use of more or different ranges of stimuli.

The existence of an association between music tempo and side of response execution leads us to think that tempo shares some features not only with the pitch of isolated tones but even with the wider domain of numbers and physical quantities. This idea agrees with the ATOM hypothesis proposed by Walsh (2003). According to this theory, time, space, and numbers share a common system for magnitude processing that is revealed by the spatial association of the response effectors.

Future research will be directed at verifying the existence of a spatial association of the response codes for tempo with the vertical alignment for both order-relevant and order-irrelevant tasks. Moreover, the presence of this association in all the examined conditions will be verified in musically trained persons.

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