## Title
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## Journal
Proceedings of the Annual Meeting of the Cognitive Science Society, 40(0)

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## Publication Date
2018

# Do Pitch and Space Share Common Code?: Role of feedback on SPARC effect

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## Abstract

Previous research shows that performance is better when a high pitch is responded with up or right responses and a low pitch is responded with down or left responses, called the spatial-pitch association of response codes (SPARC) effect. Despite the intuitive coupling of perception-action, studies investigating the SPARC effect have, however, used feedback to manipulate the stimulus-response mapping. Feedback contradicts the purpose of intuitive stimulus-response mapping by enabling short-term learning. This study primarily investigates the role of feedback on SPARC effect. We believe that feedback can facilitate incongruent mapping and can, therefore, reduce the cost between incongruent and congruent mapping resulting in a diminished SPARC effect. Our results, however, show that feedback has no influence on the SPARC effect indicating that long-term associations can not be overcome by short-term learning due to robust perception-action coupling. Further, unlike previous studies, we observed a strong horizontal SPARC effect in non-musicians as well.

**Keywords:** response selection, stimulus-response compatibility, cross-modal correspondence, pitch-space mapping, SPARC effect, feedback, dimensional overlap, automaticity, dual-route model

## Introduction

Stimulus-Response Mapping is essential for an effective response selection which is important in the course of interaction between perception and action (Fitts & Deininger, 1954; Fitts & Seeger, 1953; Kornblum, Hasbroucq, & Osman, 1990). Research has widely referred to such mappings or correspondences between stimulus and response as stimulus-response compatibility (SRC) effects. Such stimulus-response mappings exist in stimuli, ranging from non-spatial attributes such as color i.e. Simon effect (Simon, 1990), to spatial correspondence i.e. stimulus and response sharing spatial coding such as pitch and number e.g spatial-pitch or music association of response codes (SMARC or SPARC) (Lidji, Kolinsky, Lochy, & Morais, 2007; Rusconi, Kwan, Giordano, Umilta, & Butterworth, 2006) and spatial-numerical association of response codes (SNARC) respectively (Dehaene, Bossini, & Giraux, 1993). Research shows that performance is better when stimulus and response share a common coding than when they do not.

This study primarily addresses the cross-modal correspondence between pitch and space. Pitch-Space mapping was first investigated by Pratt (1930) who showed that higher pitches are perceived to originate from a higher position in space and lower pitches from a lower position. Pitch is also generally categorically referred to as “high” and “low” in many languages. Such ubiquity of linguistic association between pitch and space across languages led Stumpf (2013) to argue that pitch has no spatial characteristics and instead effective linguistic cross-modal associations occur between pitch and space. This has led to the argument that the cross-modal correspondence between pitch and space might be entirely due to language. Following Pratt (1930), other studies (Mudd, 1963; Roffler & Butler, 1968; Trimble, 1934), employing explicit linguistic responses such as high, low, ascending, descending (also called pitch metaphors) also failed to establish any intrinsic pitch-space mapping because of the aforementioned arguments. However, studies such as (Wagner, Winner, Cicchetti, & Gardner, 1981; Walker et al., 2010) showed supporting results by employing the head-turn paradigm indicating early development of pitch-space mapping and its automaticity in response. Such contradictory observations have led to subsequent investigations which aimed to filter out spatial pitch metaphors.

Studies (Beecham, Reeve, & Wilson, 2009; Lidji et al., 2007; Rusconi et al., 2006) have attempted to investigate the spatial representation of pitch by employing SRC paradigm. It seeks to remove the pitch metaphors by pairing pitch to discrete response locations i.e. by looking into spatial association between stimuli (pitches) and response locations (up vs. down & left vs. right). Hence, the task becomes a simple key-press task which does not require participants to use explicit pitch-metaphors or visuo-spatial imagery in order to give responses. Their findings support the spatial mapping between pitch and the associated response locations by showing better accuracy and faster response times (RTs) when a high pitch is responded with up or right response and a low pitch is responded with down or left response than vice-versa.

One of the cognitive foundations for SRC comes from the seminal study by Kornblum et al. (1990). They proposed a dimensional overlap model which refers to the fact that SRC effect is caused by an overlap of dimensions or categories between stimulus and response. This dimensional overlap can be caused not just by a similarity in physical categories between stimulus and response but also when they refer to the same coding. In the context of this study, we assume that pitch and response location refer to the same spatial coding that gives rise to SRC effects - referred generally as spatial pitch association of response codes (SPARC). The model proposes that when stimulus and response in SRC tasks share categories, then "*elements in the stimulus set automatically activate corresponding elements in the response set*" (Kornblum et al., 1990). When the activated and instructed response coincide, it is called congruent or compatible mapping. When they do not, it is called incongruent or incompatible mapping.

Traditionally, SRC has also often been explained by dual-route models (De Jong, Liang, & Lauber, 1994; Gevers, Caessens, & Fias, 2005) which call for two parallel routes: unconditional or automatic route and conditional or intentional route. According to the model, both routes are activated on stimulus presentation. The unconditional route automatically activates the corresponding or the compatible response whereas the conditional route is driven by task instructions. If the automatically activated response matches the response generated by the conditional route, the response is executed relatively fast. On the other hand, if the automatically activated response is in conflict with the intended response, the former is aborted and the program for intended response is initiated and executed thereby resulting in increased latency and decreased accuracy. This implies that there is a degree of automaticity that is involved in such stimulus-response mappings. Moreover, it is also important to note here that these categories or dimensions are learned over time and therefore give rise to such automaticity and subsequently the SRC effects.

Due to the automaticity caused by long-term learning, it becomes reasonable to assume that such SRC effects can be intuitively expected and investigated without any explicit manipulation of training and feedback. Why is it expected that feedback should not have been employed in SRC paradigm? Feedback has been considered as an essential factor in learning and training for effective and efficient decision making and knowledge and skill acquisition (Astwood, Van Buskirk, Cornejo, & Dalton, 2008; de Groot, de Winter, García, Mulder, & Wieringa, 2011; Hattie & Timperley, 2007). Studies have shown that feedback enables conscious or unconscious error corrections to change the course of any task performance. Positive feedback facilitates, whereas negative feedback inhibits the given task performance (Hattie & Timperley, 2007). Furthermore, it has been discussed, which of the two: a positive or negative feedback is an effective feedback? A study on lane-keeping driving simulation (de Groot et al., 2011), investigating on-target compared to the off-target feedback, shows a different impact on an immediate lane-keeping performance and a retention phase. No difference has been observed between the on-target and off-target feedback on lane-keeping performance. However, the off-target feedback showed an advantage over the on-target feedback during retention phase, indicating low sensory overload due to the constant feedback on every action. Previous findings show a relationship between learning and the nature of the feedbacks, whether it is extrinsic (augmented) or intrinsic feedback, i.e. embedded into the task itself (Anderson, 1994), its temporal placement, i.e. appearing immediately or delayed by varying number of trials (Anderson, 1994; de Groot et al., 2011; van Leeuwen, de Groot, Happee, & de Winter, 2011), and the kind of modality, i.e. visual and audio or combination of the two or proprioceptive feedback (Anderson, 1994; Goldberg & Cannon-Bowers, 2015). The aforementioned studies indicate the importance of feedback in a novel task situation for better learning and training. Therefore, it seems pointless to employ feedback in case of skilled task performances, which involve intuitive or automatic information processing such as SRC effect.

Despite automaticity in pitch-space mapping, studies investigating SPARC effect (Beecham et al., 2009; Rusconi et al., 2006) have used feedback to manipulate the stimulus-response mapping. Based on previous findings, it can be argued that feedback contradicts the purpose of intuitive stimulus-response mapping. It enables short-term learning and can, therefore, act as a strong confound. One could predict that this can cause short-term learning in the incongruent mapping. As elements in stimulus automatically activate the corresponding elements in response, feedback might not facilitate the congruent mapping as much as it might facilitate the incongruent mapping. Feedback might, therefore, strengthen the conditional route and could subsequently lead to a reduction of cost incurred between the incongruent and the congruent mapping resulting in a diminished SPARC effect.

Considering the aforementioned factor, we found it pivotal to investigate the role of feedback on SPARC effect. We hypothesize that if feedback enables learning then we will observe a reduced SPARC effect in the feedback condition. Both vertical and horizontal spatial representation of pitch is tested.

## Methodology

### Participants

We recruited 28 (14 males) participants from International Institute of Information Technology, Hyderabad for the experiment. All of them were non-musicians, right-handed and reported normal hearing. The average age was 23.9 years ranging from 18 to 29. The first language of the participants was collected. As per the informal consultation with Speech and Linguistic researchers, we found that unlike Mandarin or Cantonese, Indian languages are not tonal. Hence we did not expect any plausible effect of language. The mode of instruction in experiment was English.

### Apparatus and Stimuli

Pure tones were used for the experiment and all tones corresponded to musical notes. The tones were generated in Audacity software (Mazzoni & Dannenberg, 2000). We had C4 (261.63 Hz) as the reference tone with target tones E3 (164.81 Hz), F3# (185.00 Hz), G3# (207.65 Hz), A3# (233.08 Hz) as "*lower*" tones and D4 (293.66 Hz), E4 (329.63 Hz), F4# (369.99 Hz), G4# (415.30 Hz) as "*higher*" tones. All tones had a presentation time of 1000ms including 25ms rise and fall times, shared a constant amplitude and were presented via headphones (Sennheiser HD 202) at a comfortable listening level.

### Design and Procedure

We employed a 5 factorial mixed group design with 2 (Feedback: feedback vs. nofeedback) as between group $\times$ 2 (Pitch height: low vs. high) $\times$ 4 (Distance from the reference tone: 1, 2, 3, 4) $\times$ 2 (Response Location: up vs. down or left vs. right) $\times$ 2 (Arm position: arm vs. cross-arm) as within group factors. The design was used for both vertical and horizontal alignments. Participants were randomly assigned to the feedback and the nofeedback conditions. The experiment was divided into two sessions corresponding to two alignments with half the participants starting with the vertical alighment while the other half starting with the horizontal alignment. The order of arm position and mappings were also counterbalanced across participants. Mappings, here, refer to the congruent and incongruent conditions. Congruent condition is the result of compatible mapping of pitch height and response location i.e. higher pitch is paired with up or right response while lower pitch is paired with down or left response. While incongruent condition is the result of incompatible mapping of pitch height and response locations i.e. higher pitch with down or left response while lower pitch with up or right response.

The task was to compare the pitch of target tones with that of the reference tone. Participants had to respond whether the target tone was higher or lower in pitch than the reference and they reported their judgment by pressing the following keys: P or Q for the horizontal alignment; 6 or B for the vertical alignment. Each trial had a fixation of 300ms which was succeeded by the presentation of the reference tone and target tone one after the other. The inter-stimulus interval (time between the offset of reference and onset of target) was 300ms. Response window began at the onset of target tone itself and had an extra 1300ms, so that the participant had a total of 2300ms to respond. Feedback condition had an extra feedback window of 750ms which displayed the visual feedback: "correct" or "incorrect". The inter-trial interval was set at 1000ms. There were a total of 80 trials (10 presentations of each target tone) in a block. Hence, there were a total of 320 trials in a session corresponding to the 4 blocks (2 arm position $\times$ 2 mappings). Both accuracy and speed were emphasized and participants were urged to take breaks between the blocks. They performed the succeeding alignment after 24 hrs. Figure 1 shows schema of a single trial. Accuracy and response time (RT) were the performance measures. The experiment was conducted in a soundproof room. It was run on E-Prime psychology software (Schneider, Eschman, & Zuccolotto, 2002).

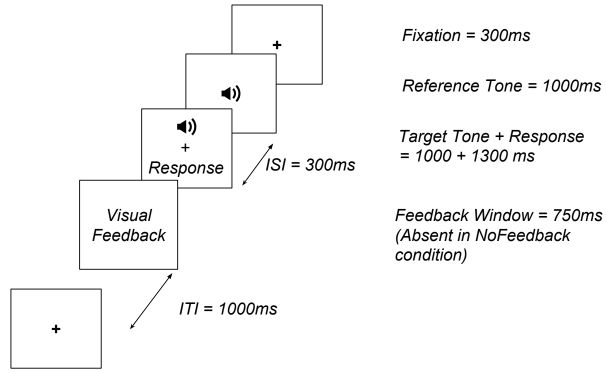


Figure 1: Schema of a single trial

## Results

Similar to Rusconi et al. (Rusconi et al., 2006), both accuracy and mean correct RTs were analyzed using a 2×2×4×2×2 mixed ANOVA on the factors mentioned in design section. RTs faster than 100ms were excluded on the assumption that no motor habituation should be considered as a response. Only correct trials RTs were included for the analysis. Both the alignments (horizontal and vertical) were separately analyzed.

### Vertical

*Accuracy Analysis* Overall accuracy was 90.1% (Feedback- 88.7% and NoFeedback- 91.6% ). The effect of distance was significant showing higher accuracy [$F(3,78) = 62.475$, $p < 0.001$] for larger distances; accuracy being significantly less for distance "1" tone (1: 78.3%, 2: 93.7%, 3: 96.5%, 4: 95.7%). Figure.2 shows the dip in accuracy for close target tones.

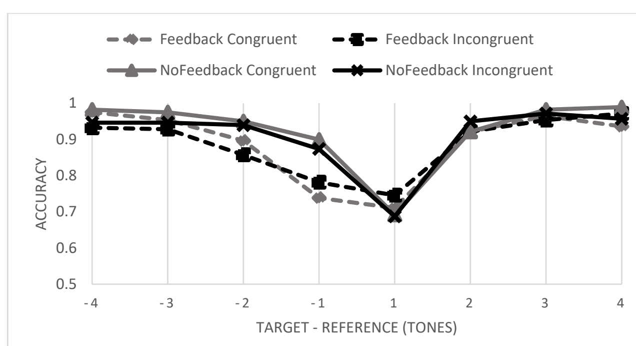


Figure 2: Accuracy as function of target tones in vertical alignment

*RT Analysis* Overall mean correct RT was 618 ms (Feedback - 596 ms and NoFeedback condition- 641 ms). The ef-

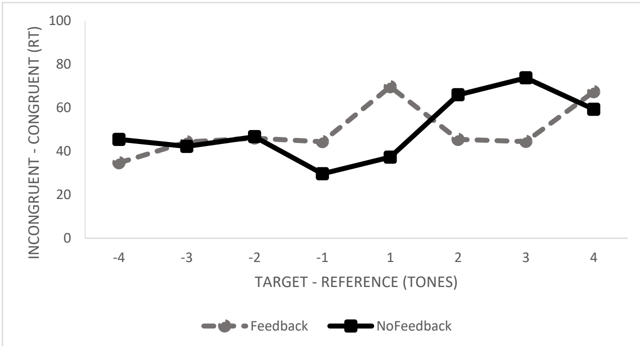


Figure 3: Mean RT difference between incongruent and congruent conditions as a function of target tones in vertical alignment

fect of distance was significant showing faster RTs [F(3,78) = 80.1, $p < 0.001$] for larger distances. Also, pitch height × response location interaction was significant [F(1,26) = 13.642, p = 0.001] with congruent faster than incongruent by 51ms indicating SPARC effect.

In both the analyses, feedback had no significant main effect. No main effects or interactions involving arm position were found. Pitch height × response location interaction was not significant in accuracy analysis.

## Horizontal

*Accuracy Analysis* Overall accuracy was 90.6% (Feedback: 89%, NoFeedback: 92%) The effect of distance was significant showing higher accuracy [F(3,78) = 64.433, $p < 0.001$] for larger distances; accuracy being significantly less for distance "1" tone (1: 77.8%, 2: 92.3%, 3: 96.2%, 4: 96%). Feedback × pitch height was significant [F(1,36) = 4.579, p = 0.042]. Further post hoc analysis revealed that lower pitches are significantly more accurate in NoFeedback than Feedback condition (5.7% advantage over higher pitches, p = 0.009). Figure. 4 shows that particularly at "-1" target tone, NoFeedback is more accurate (11.5% advantage over Feedback) independent of congruent conditions.

*RT Analysis* Overall mean correct RT was 605 ms (Feedback: 574ms, NoFeedback: 636ms). The effect of distance was significant with faster RTs [F(3,78) = 72.199, $p< 0.001$] for larger distances. Pitch height × response location interaction was also significant [F(1,26) = 9.442, p = 0.005] with congruent faster than incongruent by 44ms indicating SPARC effect. A significant main effect of arm position was found [F(1,26) = 8.43, p = 0.007] with arm faster than cross-arm by 42ms. Feedback × distance × pitch height × response location approached significance [F(3,78) = 2.604, p = 0.058]. Further post hoc analysis showed that in Feedback condition, only extreme target tones showed significant SPARC effect (+4: 53ms, p = 0.05; +3: 70ms, p = 0.008; -3: 75ms, p = 0.013; -4: 75ms, p = 0.026) whereas NoFeedback showed SPARC effect only at "-2" target tone (90ms, p = 0.001). This

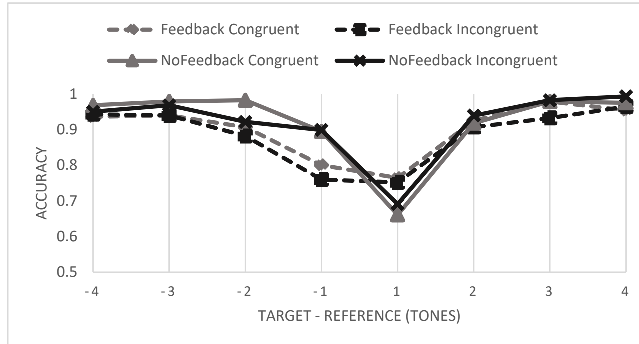


Figure 4: Accuracy as function of target tones in horizontal alignment

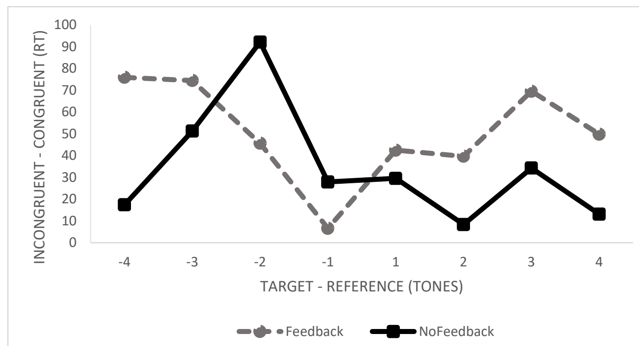


Figure 5: Mean RT difference between incongruent and congruent conditions as a function of target tones in horizontal alignment

can be easily seen in fig. 5. Feedback × arm position × pitch height × response location was significant [F(1,26) = 7.414, p = 0.011]. Post hoc revealed that in Feedback, arm condition (uncross) shows SPARC effect for both high pitches (98ms, p = 0.01) and low pitches (91ms, p = 0.004. In NoFeedback, however, cross-arm condition showed SPARC effect only for lower pitches (66ms, p = 0.015). Distance × arm position × pitch height × response location was also significant [F(3,78) = 6.635, $p < 0.001$]. Further post hoc interestingly revealed significant SPARC effect only for arm condition (uncross) albeit at extreme target tones (+4: 74ms, p = 0.026; +3: 66ms, p = 0.016; -3: 101ms, p = 0.002; -4: 66ms, p = 0.031). Feedback had no significant main effect.

In both the analyses, feedback had no significant main effect. Pitch height × response location interaction was not significant in accuracy analysis.

# Discussion

## SPARC Effect

Results show SPARC effect for both horizontal (44ms) and vertical (51ms) alignments unlike Rusconi et al. (2006) which showed (a) no SPARC effect in horizontal alignment and (b) vertical SPARC effect not just in RT but also in error analysis. The vertical SPARC effect has been consistently obtained across studies irrespective of musical training (Lidji et al., 2007; Rusconi et al., 2006). However, many studies including Rusconi et al. (2006) have found significant horizontal SPARC effect in musicians only and have attributed it to their familiarity with the piano structure which has lower pitches on the left side and higher pitches on the right side. Our study, however, shows strong horizontal SPARC effect for non-musicians as well. Lidji et al. (2007) suggest that even non-musicians can have the piano as a referent or the effect could be biased by the writing direction. However, in line with some other studies (Cho, Bae, & Proctor, 2012; Nishimura & Yokosawa, 2009), we believe that the horizontal SPARC effect might be due to the orthogonal SRC effect (Cho & Proctor, 2003). An orthogonal (vertical-to-horizontal) SRC effect is obtained when a vertically aligned stimuli is coupled with a horizontally aligned response and an advantage for the up-right and down-left pairing is observed relative to the opposite pairing. The main effect of arm position in horizontal alignment resulting in higher RTs for cross-arm condition was expected after the participants consistently reported the uncomfortability of cross-arm position. Moreover, the significant interaction of distance $\times$ arm position $\times$ pitch height $\times$ response location showed that arm condition (uncross) only contributed to the significance in SPARC effect.

There is no particular fixed pattern of SPARC effect across the target tones in both the alignments unlike Rusconi et al. (2006) which showed larger mean RT differences between incongruent and congruent for distant tones. In Figure 3, nofeedback seems to show vertical SPARC effect to be increasing with the distance of target tones but not feedback. However, the effect was more pronounced with higher-pitched tones than lower-pitched tones. In Figure 5, however, exactly the opposite seems to be true - in which horizontal SPARC effect is clearly stronger for the distant tones than the closer ones in the feedback condition while nofeedback condition shows no such trend. In addition, the horizontal SPARC effect in feedback shows symmetrical pattern w.r.t. the distance across pitches. The contradictory patterns suggest that it is difficult to establish a clear-cut pattern of SPARC effect w.r.t. distance of target tones. This, however, is not expected in the purview of dimensional overlap model. As suggested by Kornblum et al. (1990), dimensional overlap varies in degree depending on the *extent of overlap* between the shared attributes. It can therefore be assumed that dimensional overlap between pitch and response location will be more in the distant target tones than close tones. Our results, however, do not show this quite adequately. We, therefore, argue in favor of categorical / propositional spatial representation (Kosslyn, 1994) compared to analog / coordinate spatial representation (Kosslyn, 1994). In addition, the current results are consistent with Proctor and Cho (2006) finding, which suggests that pitches are encoded as binary polarities - (+) polarity for high pitches and (-) polarity for low pitches, independent of their relative positions on the pitch spectrum. In other words, if we consider pitch-response coupling as coordinate / analogous representation, i.e. mental pitch line as suggested by Rusconi et al. (2006), then larger SPARC effect would be expected with distant compared to closer tones with respect to the reference tone. However, we did not observe any significant difference in SPARC effect for distant and closer tones. Therefore, it can be concluded that the current result supports the categorical representation of pitch-response coupling than analogous representation. This, however, also opens a new line of inquiry in the SPARC research. Many studies (Cho et al., 2012; Lidji et al., 2007) have only employed distant tones to investigate the pitch-space mapping which fail to capture the varying degree of overlap spreading across the pitch spectrum.

### Feedback

Feedback, importantly, had no influence on SPARC effect. Feedback could not influence the SPARC effect in vertical alignment indicating towards a more intuitive spatial representation of pitch. This also reinforces the fact that performance in SRC tasks is largely influenced by the unconditional route due to automaticity. The automatic activation of responses due to long-term learning can not be overcome by short-term training. Dutta and Proctor (1992) demonstrated the persistence of SRC effects with extended practice. This leads us to question whether feedback is required in SRC tasks such as SPARC effect. As feedback has no role in modulating the SPARC effect, it might only result in sensory overload. We, therefore, propose that feedback should not be employed in vertical SPARC effect because of strong perception-action coupling between pitch and space.

In the horizontal alignment, Feedback $\times$ distance $\times$ pitch height $\times$ response approached significance. Post hoc revealed that significant SPARC effect came from the extreme tones and only in the feedback condition. We do not have any robust explanation for this result as of now.

NoFeedback also showed a trend of better accuracy particularly at “-1” distance tone in both the alignments. We believe that feedback resulted in sharing of confusion between closer tones “+1” and “-1” which was absent in nofeedback as participants consistently underestimated the “+1” tone. One possible explanation is that the tones were not loudness equalized which resulted in loudness acting as a confound to pure pitch perception. This is to be investigated in our future work.

## Conclusion

This study provides interesting results in the domain of pitch-space mapping literature. The novel findings are: a) no influence of feedback on vertical SPARC effect indicating strong pitch-space association due to long-term learning, and b) dominant horizontal SPARC effect in non-musicians suggesting possible orthogonality effect (Cho & Proctor, 2003); however the effect was limited to the feedback condition only. Vertical SPARC effect, however, was expected as has been shown in previous research (Lidji et al., 2007; Rusconi et al., 2006). Moreover, the asymmetric SPARC effect across tones suggest for categorical spatial representation of pitch instead of a coordinate representation.

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