The Role of Auditory Imagery and Altered Auditory Feedback in Singers' Timing Accuracy

Courtney N. Reed (1), Andrew P. McPherson (1), Marcus T. Pearce (1)

(1) School of Electronic Engineering and Computer Science, Queen Mary University of London, United Kingdom

Background
Auditory imagery allows musicians to recall mental representations of sound and has been linked to better sensorimotor coordination (Keller, 2012; Leman & Maes, 2015), effective gestural communication with other performers (Pfordresher, 2019), and the ability to perform with timing accuracy even when auditory feedback is disrupted (Brown & Palmer, 2012). The predominance of auditory imagery in the multimodal relationships driving internal temporal models however remains unclear.

Aims
This study explores how singers adapt to altered auditory feedback (AAF) using auditory imagery. We examine whether auditory imagery ability, measured using the Bucknell Auditory Imagery Scale (BAIS; Halpern, 2015), affects singers' ability to maintain temporal accuracy when singing and audiating with AAF and explore the significance of auditory imagery on timing and its role in multimodal imagery. Additionally, we focus on how imagery benefits musicians specifically, comparing timing error in a group of skilled performers.

Methods
16 unaccompanied singers performed a piece of their own choosing. AAF, including 200 and 600 ms delays and quarter- and whole-tone pitch shifts, was used in a singing task and two partial-audiation tasks designed to force reliance on auditory imagery. The coefficient of variation (CV) of sung beat onsets, representing error in timing in AAF performances, was compared to non-AAF performances. Participants were divided into two groups by their BAIS score, with the AAF condition and task as main effects on timing CV in a 2x3x4 repeated measures ANOVA, controlling for performer experience and chosen piece complexity.

Results
We find that auditory imagery on its own has limited effect on temporal variability in AAF. There were no significant interactions between BAIS and CV for pitch-shifted AAF. In individual-adjusted performances, there was a significant difference between the BAIS Groups for both 200 ms, $t(160) = 2.85$, $p = .005$, and 600 ms delays, $t(160) = 2.34$, $p = .021$. The high BAIS Group performed with similar CV across AAF conditions; however, some low BAIS group singers had less temporal deviation with delayed AAF compared to non-AAF performances. Similarly, when group-adjusted to the average CV of the whole participant cohort, analyses show CV was generally lower for both groups in delayed AAF conditions than in non-AAF performances. Performance footage reveals that participants may have employed other kinaesthetic strategies, for instance, foot tapping or body sway, to cope with delays. Additionally, many of the participants' non-AAF performances have high CV, indicating that singers were not concerned with rigid timing until presented with AAF.

Conclusion
Insignificance of auditory imagery alone suggests multimodal imagery and sensorimotor relationships may be essential and that it is not appropriate to observe timing variation without respect to these factors. As well, the performance goals may change depending on AAF; in non-AAF unaccompanied settings, singers appear to favour expression and may

have greater non-AAF "error" (Müller, Grosche, & Wiering, 2010). When delayed AAF is introduced, it may force awareness of strict timing, thus explaining why some singers achieved less temporal error.

Implications

These findings suggest that the link between auditory imagery and timing is entangled in sensorimotor relationships and encourage multimodal methodologies to examine imagery's role in musical timing; for example, models such as the Multi-Modal Imagery Association Model (MMIA; Pfordresher, Halpern, & Greenspon, 2015). Additionally, performance goals and performer priority when coping with AAF must be further examined. Similarly, this research indicates benefit in creating models of temporal drift in unaccompanied singing, comparable to existing models for tonal drift (Dai, Mauch, & Dixon, 2015).

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