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Poor-pitch singing as an inverse model deficit: Imitation and estimation

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Research on the phenomenon of poor-pitch singing is puzzling in that most of the evidence to date has ruled out rather than supported possible sources of the deficit, including pitch perception ability, motor control, and memory capacity. I propose a new way to conceptualize deficits of singing rooted in motor control research. That is, poor-pitch singing may reflect a vocal-specific deficit of inverse modeling, the ability to plan motor gestures based on an intended output.

Keywords: singing; motor control; internal models; auditory feedback; tone deafness

Singing is a non-trivial motor task in which the performer has to imitate gestures that are usually unobservable. Although the majority of the population can imitate musical pitch when singing within a semitone, a small but important portion of the population (approximately 15%) consistently sings sharp or flat by more than a semitone (see Berkowska and Dalla Bella 2009 for a review). This deficit, which we term poor-pitch singing, is accompanied by a tendency to compress the size of pitch intervals in production (Pfordresher and Brown 2007) and a general lack of consistency (imprecision) in singing (Pfordresher *et al.* 2010).

Pfordresher and Brown (2007) tested three canonical models of poor-pitch singing, each based on a particular source for the deficit. None of these models appeared to account for the deficit. One prediction, that poor-pitch singing may reflect an underlying pitch perception deficit (literal "tone deafness"), was tested by comparing singing performance with performance on a pitch discrimination task. In general, poor-pitch singers did not differ from normal singers with respect to pitch discrimination ability, a finding that has been replicated elsewhere (Dalla Bella *et al.* 2007, Pfordresher and Brown 2009). A second canonical model was based on the assumption that poor-

pitch singers are limited with respect to the range and precision with which they can vary the fundamental frequency of their voice, a motor deficit hypothesis. However, poor-pitch singers do not differ from normal singers with respect to spontaneous vocal range (Pfordresher and Brown 2007) or with respect to their ability to sustain a consistent pitch (Pfordresher and Mantell 2009), although their deficit does seem to be limited to vocal imitation of pitch (as opposed to reproducing pitch using a slider; Hutchins and Peretz in press). Finally, the notion that poor-pitch singing may reflect an underlying memory deficit was disconfirmed in that poor-pitch singers were in fact more accurate when singing melodies with a greater diversity of pitch information as opposed to monotone (single pitch) sequences.

As such three canonical models of poor-pitch singing—the perceptual deficit model, the motor deficit model, and the memory deficit model—do not account for individual differences in singing ability. As such my collaborators and I have turned to a new way of conceptualizing pitch imitation deficits in singing.

MAIN CONTRIBUTION

Based in part on the failures of the three canonical models described above, Pfordresher and Brown (2007) suggested that the source of singing deficits may lie in the conversion between perception and action that is necessary for vocal imitation of pitch. That is, poor-pitch singers may in general have no difficulty in perceiving and conceptualizing pitch information and may have no difficulty in controlling phonation as long as phonation is not intended to match a specific referent. However, when phonation has to match some predefined target (i.e. the participant is imitating), an additional step that involves translation from perception to action must occur, which is deficient in poor-pitch singers.

Internal models in motor control: Theoretical underpinnings

Recent research on motor control has adopted the notion from control theory that performers use *internal models* to control movements (see Kawato 1999 for a complete description). Internal models are based on anticipated input-output relationships within a system. Two basic sub-classes of internal models are *forward* and *inverse* models. Forward models are used to anticipate the perceptual outcome of an action. In so doing, the perceptual system compares the actual with anticipated outcome of an action to regulate the use of sensory feedback. Though forward models certainly play an important role in singing, it is unlikely that such feed-forward relationships between action and

perception account for poor-pitch singing. A more likely source of the deficit is in the second class of internal models, the inverse model.

Inverse models are used to plan motor gestures based on the anticipated outcome of an action. With respect to singing, an inverse model would allow the singer to adjust the tension of his or her vocal folds in anticipation of the pitch that would result from these muscular settings. Importantly, this process can only work if the singer has fine-grained associations between motor gestures and outputs that can work in both feed-forward and inverse directions. We suggest that poor-pitch singers may lack such associations.

Application to poor-pitch singing

We suggest that a poor-pitch singer is unable to control the fundamental frequency of their voice in the service of matching a specific output, though they may be able to control their voice in other circumstances and may even be able to appropriately gauge whether their own produced pitch appropriately matches what they hear (e.g. if auditory feedback is altered).

In one sense, this account is associationist, in that a deficient internal model might result from poorly formed associations between perception and action. However, an important constraint is that the deficit is unidirectional, with singers being unable to plan actions based on anticipated outputs while being able to predict outputs based on their produced actions. Moreover, it is not a foregone conclusion that such a deficit, should it exist, is rooted in learned associations as opposed to one's genotype, given evidence that music-specific deficits can be highly heritable (Peretz *et al.* 2007).

The hypothesis that poor-pitch singing is an inverse model deficit leads to three critical predictions. First, and most obvious, it predicts that singing deficits should appear only during imitative tasks and may not appear during non-imitative perceptual, motor, or even sensorimotor tasks. Second, the imitative deficit of poor-pitch singing need not be music-specific, though it may be a vocal-specific deficit. Third, singing-related deficits may be enhanced in situations where perception/action associations are less well formed but may be reduced when perception/action associations are better formed.

Relationship to Pfordresher and Brown (2007)

An earlier version of this hypothesis was introduced by Pfordresher and Brown (2007), referred to there as the "mis-translation" deficit. That is, perceptual pitch events are associated with inappropriate motor events. This model, though related to the one proposed here, is different in that it suggests

a more constrained deficit. Specifically, the notion of "translation" suggests that pitch event *X* will be mapped onto motor gesture *X'* under all circumstances. This prediction is parsimonious and it accounts for the fact that singers are often consistently sharp or flat across repeated productions (Pfordresher and Brown 2007). However, this account has difficulty with other results, even those found in the paper in which the hypothesis was proposed. Specifically, it is difficult to reconcile the mis-translation hypothesis with compression of pitch intervals (Dalla Bella *et al.* 2009, Pfordresher and Brown 2007), with the fact that singing out of tune often is accompanied by imprecision (Pfordresher *et al.* 2010) and with the fact that patterns of sharp versus flat singing are mediated by the relationship between the imitated pitch and the pitch an individual finds most comfortable to sing (Pfordresher and Brown 2007).

In light of these weaknesses, the current hypothesis offers a prediction that is more flexible with respect to the specific outcomes of the system, yet still constrained with respect to the conditions under which deficient singing should be found. I now consider what existing empirical support there is for the current hypothesis and consider avenues for future research.

Empirical support

Recent research has offered support for the three critical predictions listed above. Prediction one is based on negative evidence, absence of deficits in non-imitative tasks. Evidence that poor-pitch singers are not deficit in non-imitative motor tasks was described earlier. More recently, my lab has investigated the effect of alterations to auditory feedback during singing, in samples that include both normal and poor-pitch singers. We found that the relationship between mistuning in singing and the disruptive effect of alterations to feedback pitch was negligible (r^2=0.01).

The second two participants are more amenable to empirical testing in that they are based on positive effects. With respect to the prediction that poor-pitch singers have a deficit of vocal imitation that is not necessarily music specific, we have found that poor-pitch singers show strikingly similar deficits when imitating intonational pitch in speech (Pfordresher and Mantell 2009).

In order to address to the third prediction (reduced deficit when associations are better formed), my lab has recently run a series of studies examining vocal imitation of one's own performances versus those of others. The inverse model deficit hypothesis suggests that poor-pitch singers may be better able to imitate their own performances than those of others, based on having

greater familiarity with their own vocalizations. Preliminary results verify this prediction. Interestingly the advantage to imitating one's own performances persists even when recordings are transformed to be a complex tone lacking vocal timbre. Thus, the benefit of self-imitation is not entirely due to timbre matching or to voice-specific recognition cues.

IMPLICATIONS

The study of poor-pitch singing from a cognitive perspective is very recent (the tradition in music education dates back much further, cf. Welch 1979) and holds great promise. In keeping with this perspective, I argue that one's singing ability is not simply a manifestation of music-specific talents, practice, or aesthetic sensibility, though unquestionably singing is influenced by all these things. My point is that singing, as a complex motor task, to a large degree reflects the demands of motor control, memory, perception, and sensorimotor integration that are common to a wide range of abilities. Thus a starting point to understanding poor pitch singing involves addressing whether the deficit lies in any of these basic, domain-general functions.

As stated before, the inverse model deficit hypothesis in its current form makes predictions about the conditions in which poor-pitch singing will be observed but does not commit to specific patterns of behavior. Future research will be aimed at this latter goal. Specifically, we suspect that manifested behaviors reflect attempts to *estimate* the outcome of one's motor gestures, based on an unreliable internal model, a prediction that is consistent with results suggesting that poor-pitch singers are imprecise in their production (Pfordresher *et al.* 2010).

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References

Berkowska M. and Dalla Bella S. (2009). Acquired and congenital disorders of sung performance: A review. *Advances in Cognitive Psychology*, *5*, pp. 69-83.

Dalla Bella S., Giguere J. F., and Peretz I. (2007). Singing proficiency in the general population. *Journal of the Acoustical Society of America*, *121,* pp. 1182-1189.

Dalla Bella S., Giguere J. F., and Peretz I. (2009). Singing in congenital amusia. *Journal of the Acoustical Society of America*, *126,* pp. 414-424.

Hutchins S. and Peretz I. (in press). A frog in your throat or in your ear? Searching for causes of poor-pitch singing. *Journal of Experimental Psychology: General.*

Kawato M. (1999). Internal models for motor control and trajectory planning. *Current Opinion in Biology, 9*, pp. 718-727.

Peretz I., Cummings S., and Dube M. P. (2007). The genetics of congenital amusia: A family-aggregation study. *The American Journal of Human Genetics, 81,* pp. 582-588.

Pfordresher P. Q. and Brown S. (2007). Poor-pitch singing in the absence of "tone deafness". *Music Perception*, *25,* pp. 95-115.

Pfordresher P. Q. and Brown S. (2009). Enhanced production and perception of musical pitch in tone language speakers. *Attention, Perception, and Psychophysics*, *71,* pp. 1385-1398.

Pfordresher P. Q., Brown S., Meier K. M., Belyk M. *et al.* (2010). Imprecise singing is widespread. *Journal of the Acoustical Society of America*, *128,* pp. 2182-2190.

Pfordresher P. Q. and Mantell J. (2009). Singing as a form of vocal imitation: Mechanisms and deficits. In J. Louhivouri *et al.* (eds.), *Proceedings of the 7th triennial conference of European Society for the Cognitive Sciences of Music* (pp. 425-430). Jyväskylä, Finland: Jyväskylä University.

Welch G. F. (1979). Poor pitch singing: A review of the literature. *Psychology of Music, 7*, pp. 50-58.