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Effects of altered auditory feedback across effector systems: Production of melodies by keyboard and singing

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ABSTRACT

We report an experiment that tested whether effects of altered auditory feedback (AAF) during piano performance differ from its effects during singing. These effector systems differ with respect to the mapping between motor gestures and pitch content of auditory feedback. Whereas this action-effect mapping is highly reliable during phonation in any vocal motor task (singing or speaking), mapping between finger movements and pitch occurs only in limited situations, such as piano playing. Effects of AAF in both tasks replicated results previously found for keyboard performance (Pfordresher, 2003), in that asynchronous (delayed) feedback slowed timing whereas alterations to feedback pitch increased error rates, and the effect of asynchronous feedback was similar in magnitude across tasks. However, manipulations of feedback pitch had larger effects on singing than on keyboard production, suggesting effector-specific differences in sensitivity to action-effect mapping with respect to feedback content. These results support the view that disruption from AAF is based on abstract, effector independent, response–effect associations but that the strength of associations differs across effector systems.

1. Introduction

When individuals produce a sequence of motor actions across a span of time, these actions are accompanied by perceptual events that result from actions. In certain domains, such as speaking and music performance, these perceptual consequences constitute goals for actions, and auditory feedback thus provides information about whether the appropriate goal has been met. Based in part on these observations, some have suggested that a close coupling exists between the mental representations used to plan actions and the representations used to monitor the consequences of these actions (e.g., Hommel, Muessler, Aschersleben & Prinz, 2001; MacKay, 1987; Prinz, Aschersleben, & Koch, 2009). If, as these theories suggest, perception and action share a common representation, then fluent production should depend on the coordination of perceptual feedback events with actions. This reliance is demonstrated by the disruptive effects of altered auditory feedback (AAF) during the production of speech and music (for reviews see Finney, 1999; Howell, 2004; Pfordresher, 2006; Yates, 1963). Disruptive effects of AAF differ from the effects of masking or removing auditory feedback, which have been found to yield negligible effects in musical keyboard production (Finney & Palmer, 2003; Pfordresher, 2005; Repp, 1999), and have been found to yield considerably smaller effects on singing than effects of AAF (Mürbe, Friedemann, Hofmann, & Sundberg, 2002, 2004; Ward & Burns, 1978).

The fact that production relies on sensorimotor coordination is interesting in itself, but perhaps a more compelling question is, how can AAF interference effects inform models of cognitive organization for perception and action? A related issue that has received differing support has to do with the role of different effector systems (i.e., the motor systems responsible for action production): whereas some research suggests that perception–action associations exist at an abstract level of representation that may extend across effector systems (e.g., Cohen, Ivry, & Keele, 1990; Grafton, Hazeltine, & Ivry, 1998; Howell, 2001; MacKay & Bowman, 1969; Palmer & Meyer, 2000), evidence also exists for reduced effects of sensorimotor interactions after switching response mode (Yamaguchi & Proctor, 2009). In addition, some neuroimaging evidence is consistent with the idea that perception–action associations are effector specific (e.g., Buccino et al., 2001). The research summarized in this paper addresses the degree to which effects of AAF generalize across two effector systems that are used to produce music: The hand–digit system (used for keyboard performance) and the vocal system (used for singing). Broadly speaking, effector independent effects of AAF suggest that disruption occurs at an abstract level of representation and are based on a general sensitivity to correlations between perception and action. By contrast, effector specific effects may reflect task-specific learned associations.

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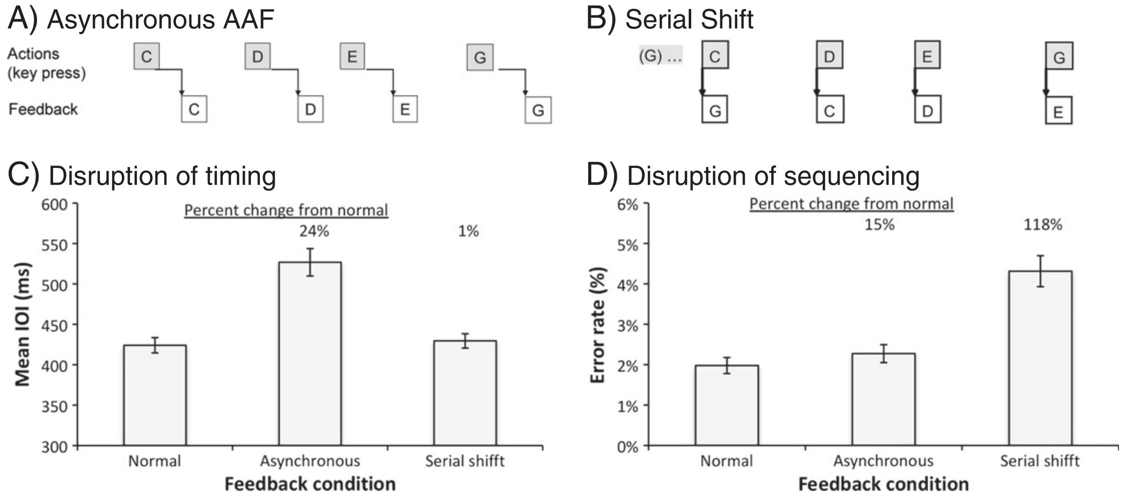

Fig. 1. Schematic illustrations of altered auditory feedback (AAF) manipulations that result in asynchronies (A) or alterations of contents (B) between perception and action. Gray boxes indicate the timing (left-to-right) and contents (letters) of produced actions. In this context, "contents" refers to a motor gesture (e.g., a piano key press) that under normal circumstances would lead to the pitch indicated by the letter. White boxes refer to timing and content of resulting perceptual events. Lower plots show pooled means (see text) across normal and AAF conditions that represent effects on timing (C) and the accuracy of sequencing (D). Error bars represent the between-participants standard error of the mean.

1.1. Dissociation of sequencing and timing effects from AAF

The most well known form of AAF is delayed auditory feedback, in which a constant time lag is added to the onsets of perceptual feedback during production. Delays within the range of 100–400 ms can disrupt the performance of music on a keyboard, leading to slowed production (e.g., Finney, 1997; Gates, Bradshaw, & Nettleton, 1974), increased errors (e.g., Finney, 1997), and increases in timing variability (e.g., Pfordresher & Palmer, 2002). Similar effects have been found in speech (e.g., Black, 1951; Fairbanks & Guttman, 1958; Lee, 1950) and in other musical instruments (e.g., Havlicek, 1968).

More recent research on the effects of AAF during music production has sought to control the temporal coordination between actions and auditory feedback. Specifically, one can partition the effects of traditional delayed auditory feedback into two possible components: *feedback synchrony* and *feedback contents*. Illustrative schematic examples are shown in Fig. 1 (for further discussion, see Pfordresher, 2006; Pfordresher & Kulpa, 2011). A manipulation of feedback synchrony (Fig. 1A) causes feedback events (here, musical tones), to lag behind the actions associated with their production (e.g., a key press on a keyboard) yet occur before the next produced action. Importantly, in such circumstances an action is always followed by the anticipated event category (e.g., pressing the key for middle C leads to the associated pitch for middle C). Thus, the disruptive effects of such alterations can only be attributed to onset timing.[1]

A qualitatively different kind of AAF manipulation involves changing the contents of auditory feedback while maintaining synchronization between perception and action (or asynchronies must be too small to be noticed). In such cases, disruption must occur because the event category represented by auditory feedback differs from the anticipated event category. When participants experience serially shifted AAF, the onset time of a motor act (a key press on the keyboard, or the initial phonation of a syllable) coincides with a feedback event whose pitch matches a pitch from a different serial position in the sequence. The serial separation between actions and feedback events is kept constant; Fig. 1B shows a serial shift with a lag of 1, where each action produces the pitch associated with the previous serial position. Interestingly, other manipulations to feedback contents, such as presenting a randomly selected pitch or transposing the feedback melody, do not disrupt production (Finney, 1997; Pfordresher, 2005, 2008).

In one sense, AAF that is serially shifted by a lag of 1 is similar to asynchronous feedback, in that both manipulations present feedback information "too late." However, they differ in three critical respects. First, as described above, the fact that serial shifts are synchronous with actions means that disruption must be based on the mismatch between feedback contents and expected contents, whereas the same basis cannot be true of asynchronous feedback (as manipulated here). Second, the effects of these manipulations differ qualitatively (as described below). Finally, serial shifts that present future events (reported in Pfordresher & Palmer, 2006) lead to levels of disruption similar to that of serial shifts that present past events. Thus these manipulations of AAF differ in theoretically important qualitative respects.

Manipulations of feedback synchrony and feedback contents have qualitatively distinct effects on musical keyboard production, as shown in the lower part of Fig. 1. The illustrated data were pooled across three studies in which participants experienced normal feedback, asynchronous feedback (with delays equal to 33% of IOIs in a trial), and serial shifts of lag 1 (Benitez, 2005; Pfordresher, 2003, Experiment 4; Pfordresher et al., 2010). Participants in these experiments included pianists (with at least 8 years of formal training on the piano, N = 28) and non-pianists (N = 101) who performed short melodies from memory that were unfamiliar before learning. Both groups demonstrated the same pattern of results. Fig. 1C shows how asynchronous and serially shifted AAF influence production rate, measured by the mean of produced inter-onset intervals (IOIs, the time between successive key presses) in a trial. Importantly, participants were instructed to maintain a target tempo of 500 ms during AAF (though participants often exceed this rate when performing with normal feedback); higher mean IOIs represent greater slowing of performance timing. As can be seen, asynchronous feedback considerably slows production compared to normal feedback, whereas serial shifts have negligible effects on produced timing.[2]

[1] Traditional delayed auditory feedback using fixed delays often leads to asynchronous AAF. However, if the time of the delay is equal to the time between produced events, then delayed auditory feedback can lead to relationship between perception and action more like the serial shift of feedback (shown in Fig. 1B).

[2] The percent of change between AAF performance and normal feedback performance is calculated as $[((\text{AAF} - \text{normal})/\text{normal}) \times 100]$. This simple measure of performance change allows comparisons of these pooled data with the data from the current study by controlling for differences in base (normal) levels of performance across participants (see Section 3).