

## Can altered auditory information affect planning? Evidence from music performance

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**Abstract.** In the EXPLAN architecture (target article), altered recurrent auditory information (ARAI) is presumed to influence the execution but not planning of speech. This conclusion stems from evidence that the influence of ARAI is limited to timing relationships between perception and action. However, recent evidence documents disruption of musical keyboard performance from certain manipulations of perceived pitches, even when sounds are synchronized with key presses. These results lead to a proposed extension of EXPLAN.

**Keywords:** EXPLAN, altered recurrent auditory information, delayed auditory feedback, frequency shifted feedback, EXPLAN.

### 1. Comments on Howell (2004a)

The EXPLAN model proposed by Howell (2004) in the target article and expanded on elsewhere (Howell, 2002; 2004b; Howell & Au-Yeung, 2002), makes a parsimonious claim about the role of sound during sequence production: When producing a sequence, people are sensitive to timing relationships between perception and action but are insensitive to whether the planned contents resulting from actions (categories of sound, e.g., phonemes or musical pitches) match perceived contents in resulting auditory information. This claim stems from past research that demonstrated disruption from delayed auditory feedback (DAF), even when the contents of auditory information failed to resemble the contents of planned events (i.e., speech, Howell & Archer, 1984). Based on this logic, people should *not* be affected by altered recurrent auditory information (ARAI) manipulations that alter the contents of sound while maintaining synchrony between actions and sound. This commentary discusses two findings from the domain of musical keyboard performance that do demonstrate sensitivity to the contents of sound during production.

Many studies have demonstrated commonalities across music and speech production, suggesting that results from one domain may inform the other. For instance, evoked potentials reveal similar responses to structural deviations in music and speech (Besson & Schön, 2001; Patel, 1998), serial ordering errors follow similar patterns in speech and music (Palmer & Pfordresher, 2003), and recent neuroimaging research has revealed activation in “speech” areas during music listening (Levitin & Menon, 2003). Moreover, ARAI yields similar patterns of disruption across music and speech production tasks (see Pfordresher, 2003, for a review).

One recent finding demonstrates that ARAI can disrupt music performance when only the contents of auditory information are altered (Pfordresher 2003, Experiment 2). In that experiment, ARAI was synchronous with each key press but presented a pitch that had been produced one, two or three events in the past (implemented using FTAP, Finney, 2001). Because this disruption resulted neither from altered onset synchrony between perception and action, nor from hearing multiple sounds, it is not comparable to the effects of DAF or FSF summarized by Howell (target article).

A second relevant finding comes from an earlier study by Finney (1997), who examined performances of Bach pieces by trained pianists, under conditions of DAF (delay of 200 ms), and with ARAI that presented randomized pitches in synchrony with key presses. Randomized pitches did not disrupt production, whereas DAF did, as predicted by EXPLAN. However, combinations of DAF and randomized pitch produced *less* disruption than DAF on its own. Pfordresher (2003, Experiment 3) also found reduced disruption when both contents and onset times of auditory events were altered relative to produced actions. Reduction of disruption in these conditions contrasts with the results of Howell and Archer (1984), and again suggests that performers are sensitive to the contents of auditory information.

What implications do these results have for EXPLAN? They suggest that ARAI can affect planning, given that alterations of contents on their own can disrupt production. However, the emerging story is too complex for feedback-control theories that were used to connect ARAI with planning in the past (Black, 1951). A feedback-control theory would predict similar disruption from manipulations of

contents implemented by Pfordresher (2003) and Finney (1997). Obviously, a more complex approach to planning is required.

One framework that may account for these data proposes that perception and action share a common incremental representation. Much research on perception and action suggests that both behaviors share a common hierarchical representation (Hommel, Müsseler, Aschersleben & Prinz, 2001; MacKay, 1987). Incremental plans characterize the use of hierarchical representations in real time (e.g., during planning). During incremental planning, the activation (mental accessibility) of sequence events is not limited to the current event, but also includes surrounding events (e.g., the range model of planning, Palmer & Pfordresher, 2003; cf. Lashley, 1951). Thus, it is likely that speakers both plan and perceive real-time auditory sequences in an incremental fashion during production, having access to past, present, and future events at any given point in time.

If perception and action share a common incremental representation, then the time course of action planning may be disrupted when performers hear auditory events intended for other sequence positions (as in Pfordresher, 2003). In such situations, feedback events would match accessible events in the plan other than the current event. The result would be that activation is added to unintended sequence events, disrupting the distribution of event activations. Alternatively, randomized pitches (Finney, 1997), and contents transformed to match a different kind of signal (Howell & Archer, 1984), would yield nebulous influences on planning because they do not match accessible events.<sup>1</sup>

The incremental planning account summarized above, however, does not account for the fact that ARAI that combines DAF with randomized pitches reduces disruption relative to DAF alone (Finney, 1997). The two-tiered framework of EXPLAN can help here. Perhaps production is maximally disrupted when ARAI differs from production with respect to either planning (via alterations of contents), or execution (via alterations such as DAF), but not both. This possibility receives some support from differences found with respect to different measures of disruption. Although Howell (2004a) focuses on how ARAI affects production rate (e.g., global slowing), many experiments document increases in error rates from ARAI (e.g., in speech, Fairbanks & Guttman, 1958; MacKay, 1968; 1970; Robinson, 1972). Moreover, analyses of different types of disruption can prove illuminating. For instance, Pfordresher (2003) found that asynchronous ARAI (similar to DAF) slowed production rate, whereas alterations of contents increased error rates.<sup>2</sup> It is possible that this dissociation in measures of disruption results from interactions between planning and execution components in EXPLAN.

To summarize, these results suggest that alterations of auditory feedback can disrupt the process of planning if the alterations disrupt sequential relationships between perception and action, and that these kinds of alterations may lead to increased errors in production. It is not presently known whether these results generalize to speech, or to individuals with disorders such as stammering. If these results do generalize, a reassessment of EXPLAN's architecture may be in order in which feedback contents interact with the incremental planning of actions, and performers respond to perception/action similarity based on interacting timing and sequential information.

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#### **Footnotes**

<sup>1</sup> Recent unpublished research has combined the randomized pitch condition of Finney (1997) with alterations used by Pfordresher (2003) in the same session, to confirm that differences between experiments do not account for the dissociation. This recent work has furthermore demonstrated the dissociation for individuals without formal piano training in a simplified music production task (Pfordresher, in preparation).

<sup>2</sup> The manipulations of ARAI used in this experiment differed somewhat from standard DAF and allowed a cleaner separation of ARAI influences on timing versus contents.