CHAPTER 1

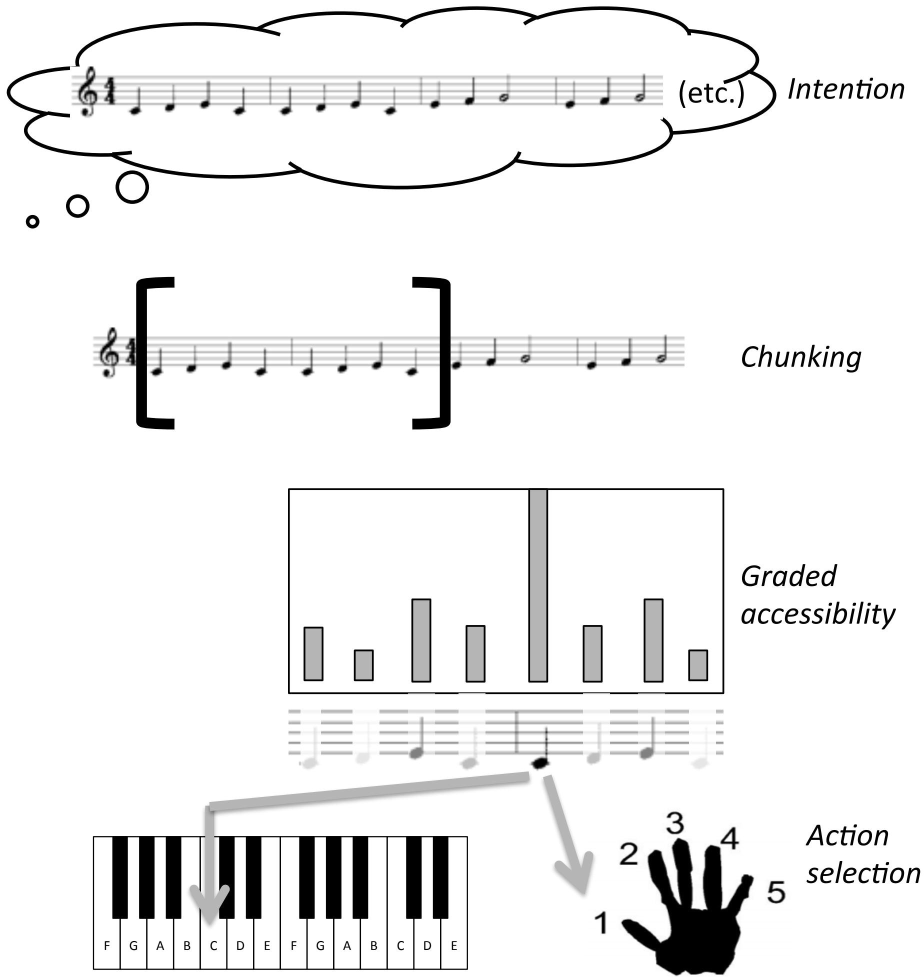


Figure 1.1: The formation of an action plan in music performance. See text for details.

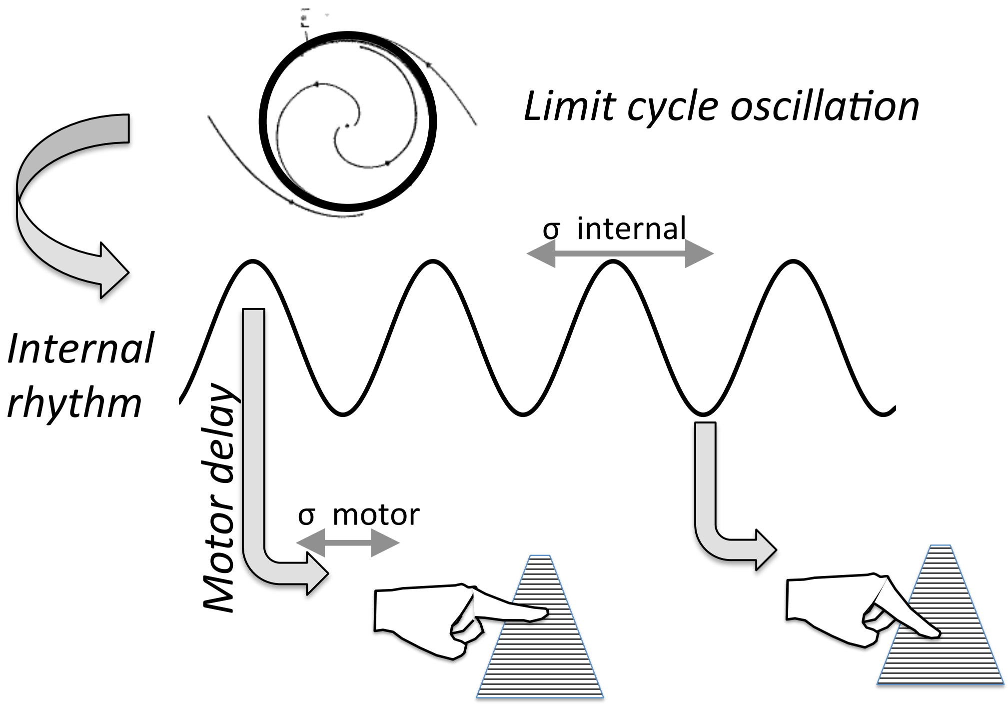


Figure 1.2: Temporal control and variability sources in music performance.

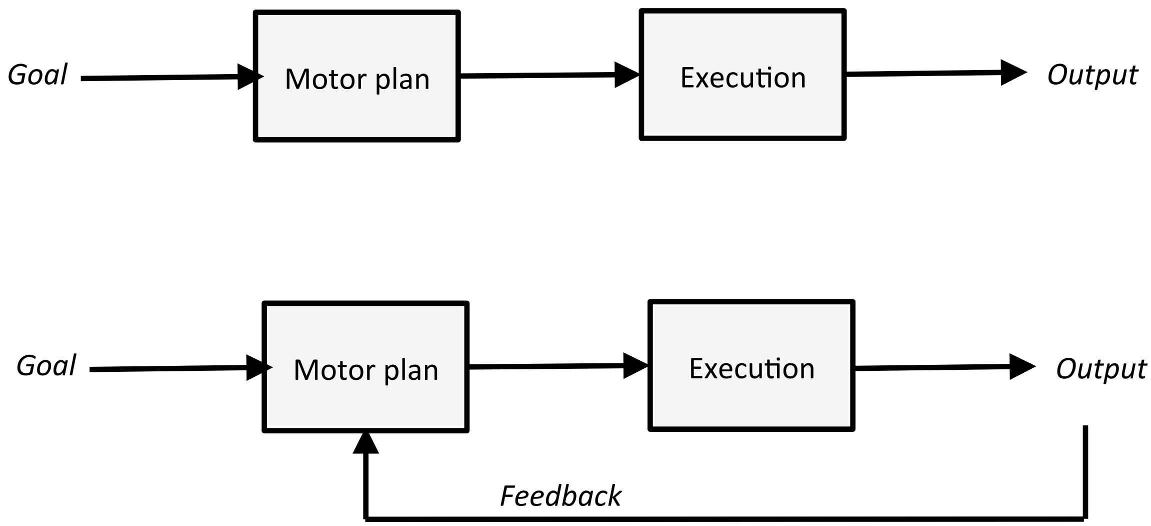


Figure 1.3: Highly simplified control system reflecting open loop (top) versus closed)-loop (a.k.a. "feedback control", bottom) control.

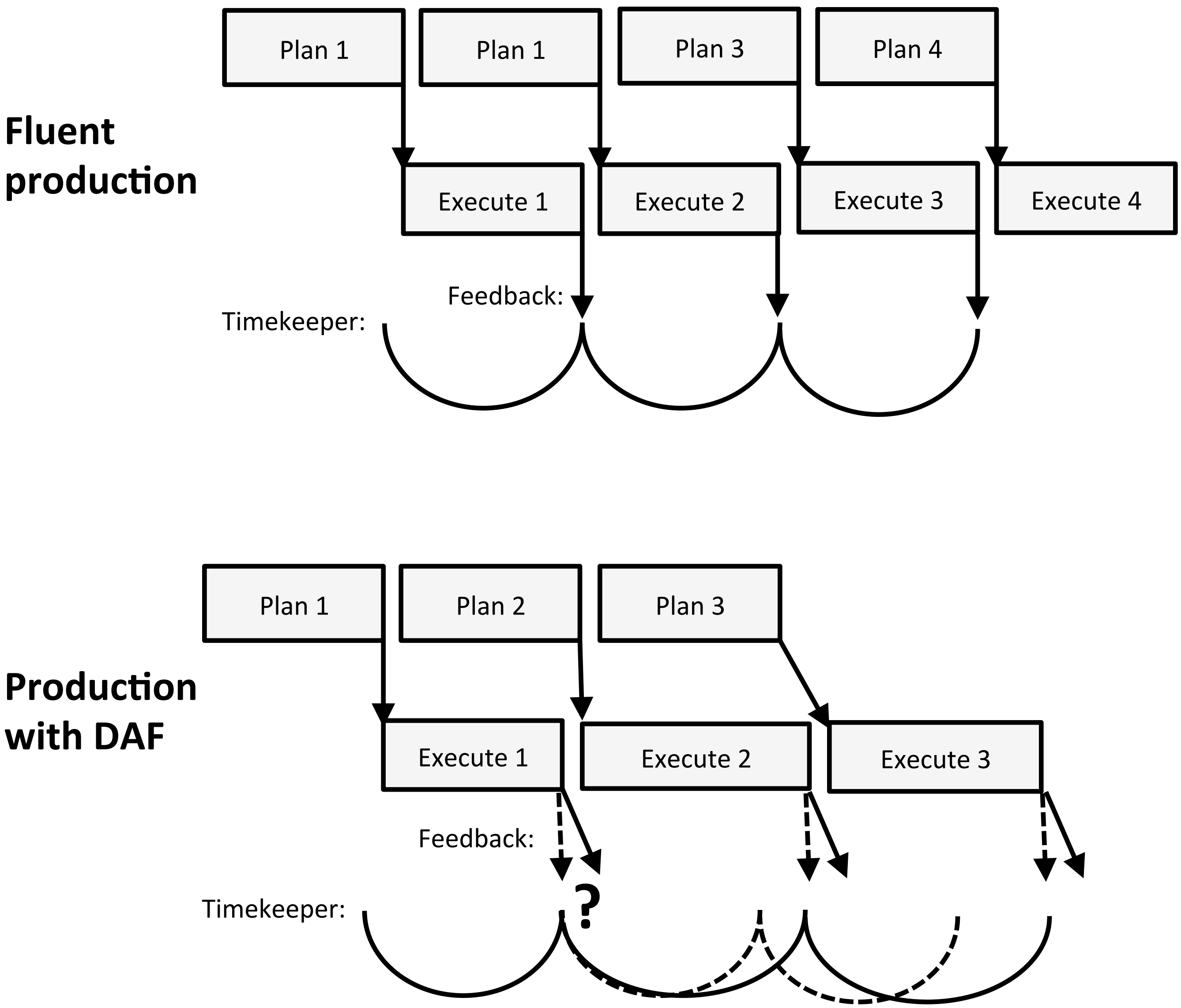


Figure 1.4: The EXPLAN theory of speech planning and role of auditory feedback. Numbers indicate sequenced events (e.g., syllables). Dashed arrows indicate anticipated timing of events given the timing of execution, whereas dark arrows indicate the timing of auditory feedback. The effect of DAF on the timekeeper is show by comparing the intended timing of execution (dashed line) to the actual timing of execution that results from asynchronies between auditory feedback and the intended timing of actions.

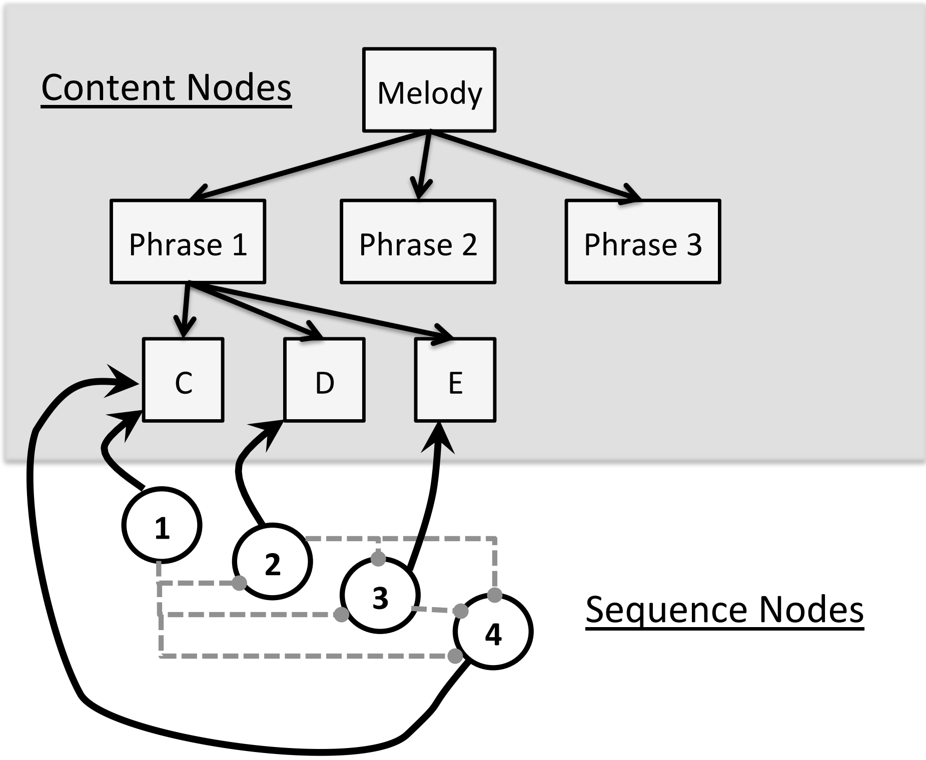


Figure 1.5: Illustration of Node Structure Theory as applied to a musical context: The first phrase of *Frere Jacques* (cf. Figure 3.2 from MacKay, 1987, p. 54). Content nodes are shown as rectangles over the grey background, whereas sequence nodes are shown as circles. A subset of the phrase hierarchy within the entire melody is shown at the top two levels of content nodes, as well as the pitch content within phrase 1, denoted by standard pitch labels. The 4 sequence nodes have lateral inhibitory connections (dotted grey lines) that lead to ordering of the associated content nodes, with sequence/ content associations illustrated by curved arrows. Timing nodes (not shown) would determine the activation timing of successive sequence nodes.

CHAPTER 2

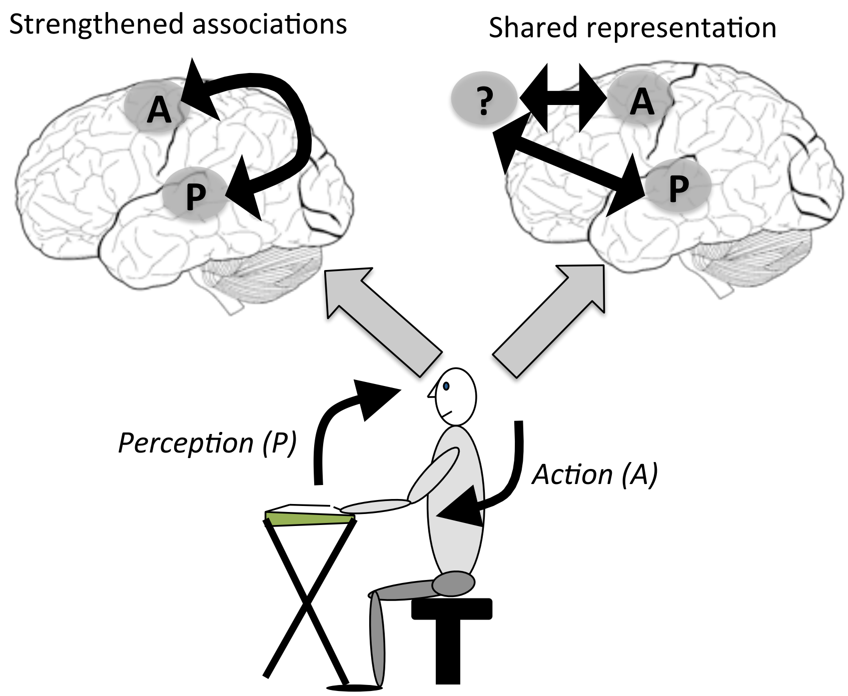


Figure 2.1: Two possible ways that musical experience performing a keyboard (lower) may facilitate associations between action planning (A) and perceptual feedback (P). Learning may enhance associations between representations used exclusively for perception or action (upper left), or may lead to the formation of shared multi-modal representations (upper right).

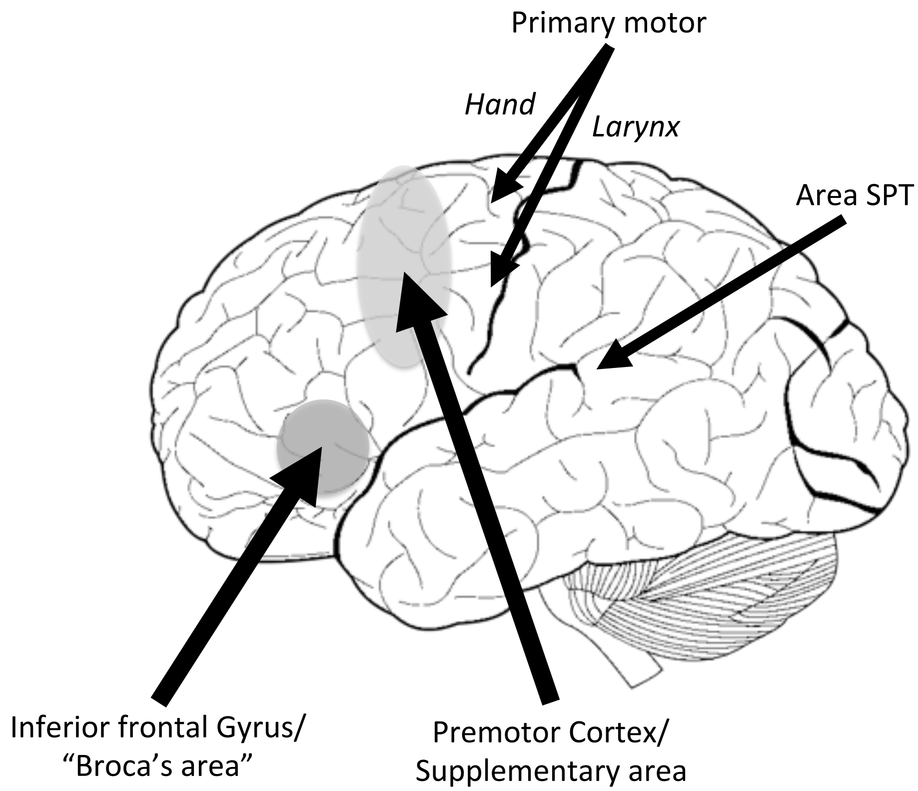


Figure 2.2: Approximate location of brain areas exhibiting motor responses during music perception after training in four longitudinal studies (Bangert et al., 2005; Baumann et al., 2007; Chen et al., 2012; Lahav et al., 2007; Mutschler et al, 2007). Darkness reflects agreement of location across studies, which was greater for inferior frontal gyrus, which was also found in a study involving non-musical auditory-motor associations (McNamara et al., 2008). Other relevant brain areas are highlighted with arrows.

CHAPTER 3

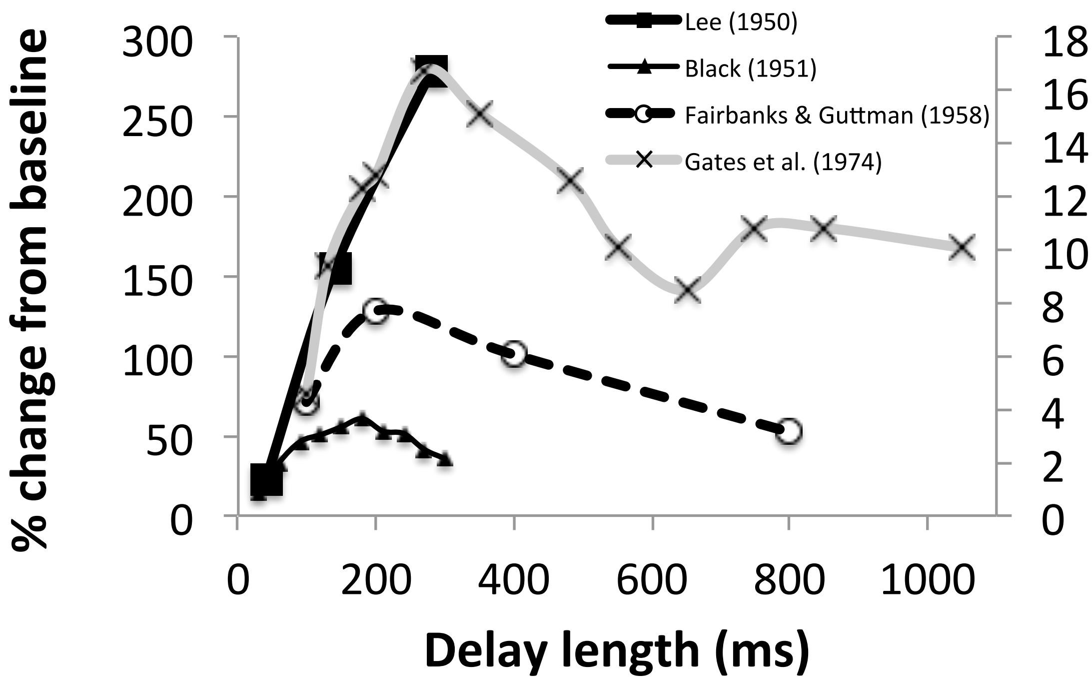


Figure 3.1: Results from four early studies of DAF. Means from Gates et al (1974) are shown on the right-side Y-axis.

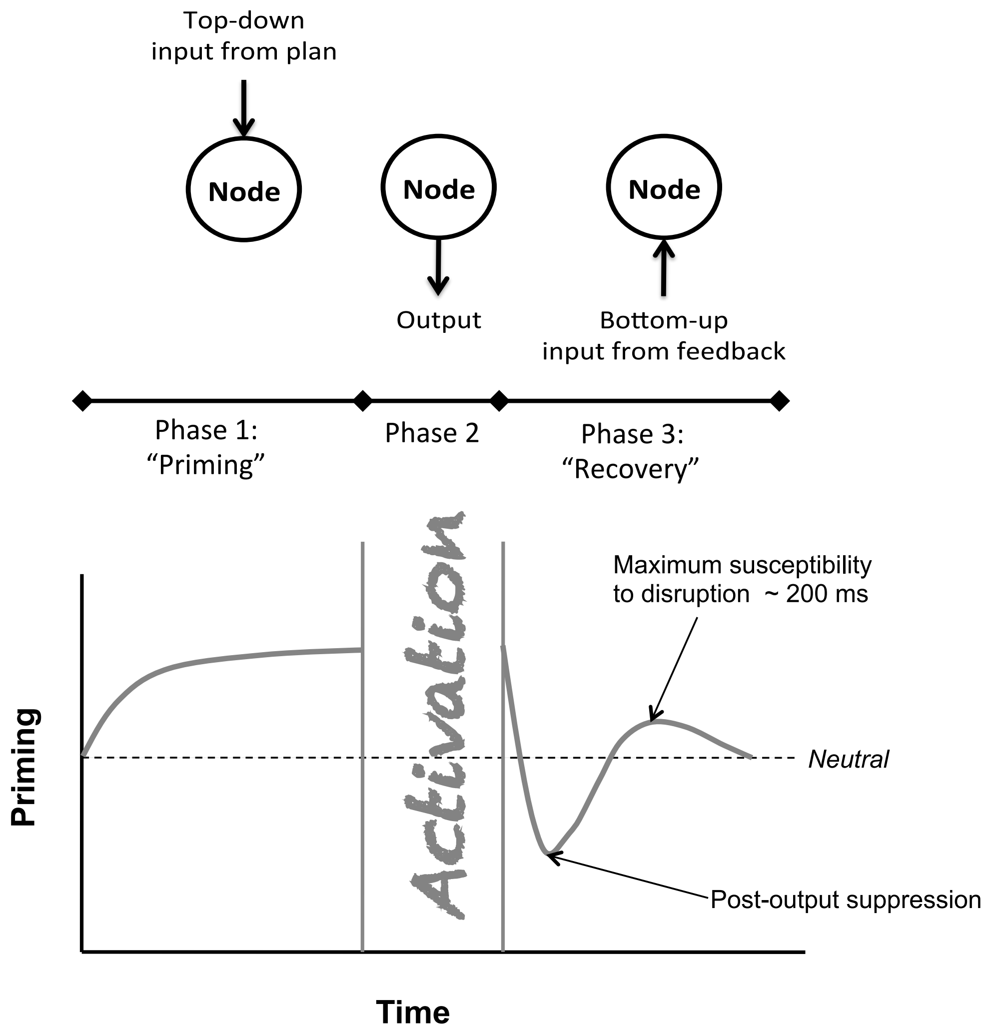


Figure 3.2: Illustration of Node Structure Theory's predictions for DAF effects, based on the node-recovery cycle, shown in the lower panel. This cycle is divided into three phases, as illustrated by the middle bar, and relates to the types of processing done within a single node, which is illustrated at the top.

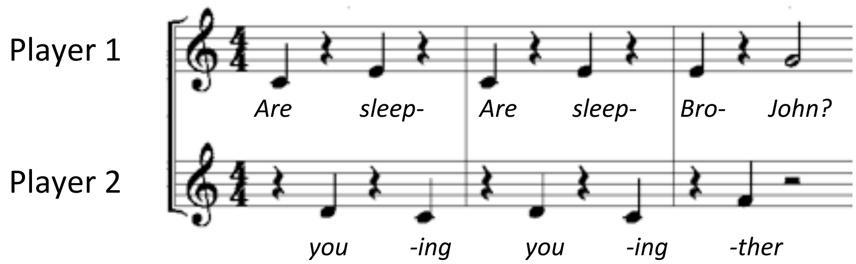


Figure 3.3: The phenomenon of hocketing, shown in musical notation. The two parts shown alternate in order to collectively produce the melody.

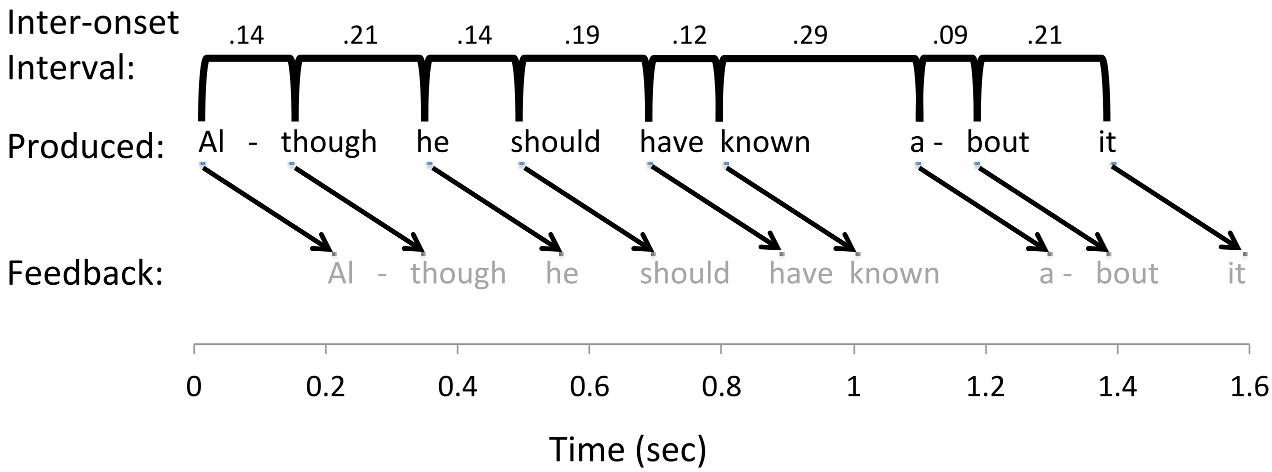


Figure 3.4: Timing of read speech by the author for a portion of the stimuli used in MacKay (1968), along with the approximate timing of syllables in auditory feedback given a 200ms delay, shown in grey text.

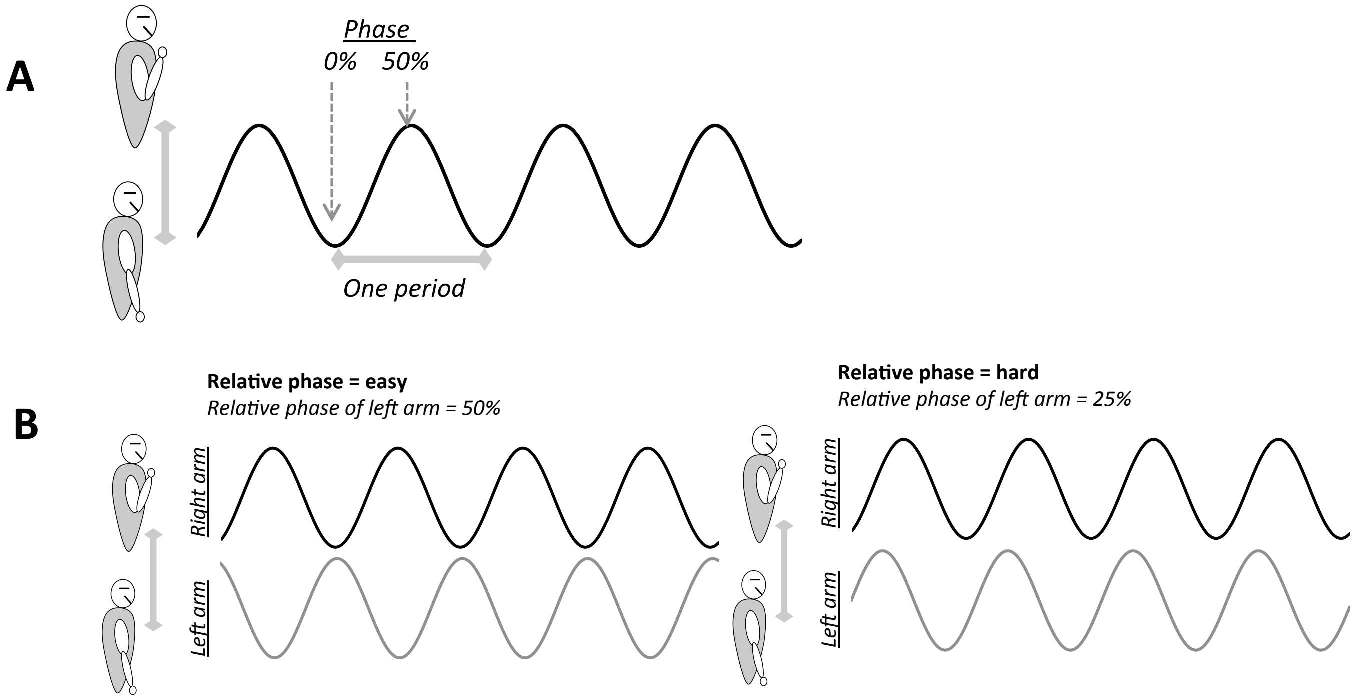


Figure 3.5: The phase and period of rhythmic arm movements in the sagittal plane (A). Examples of bimanual coordination where the relative phase of the left arm varies with respect to the right arm (B). Right arm trajectories are represented by the dark lines and left arm trajectories by the grey line, with peaks representing flexion and valleys representing extension in the sagittal plane.

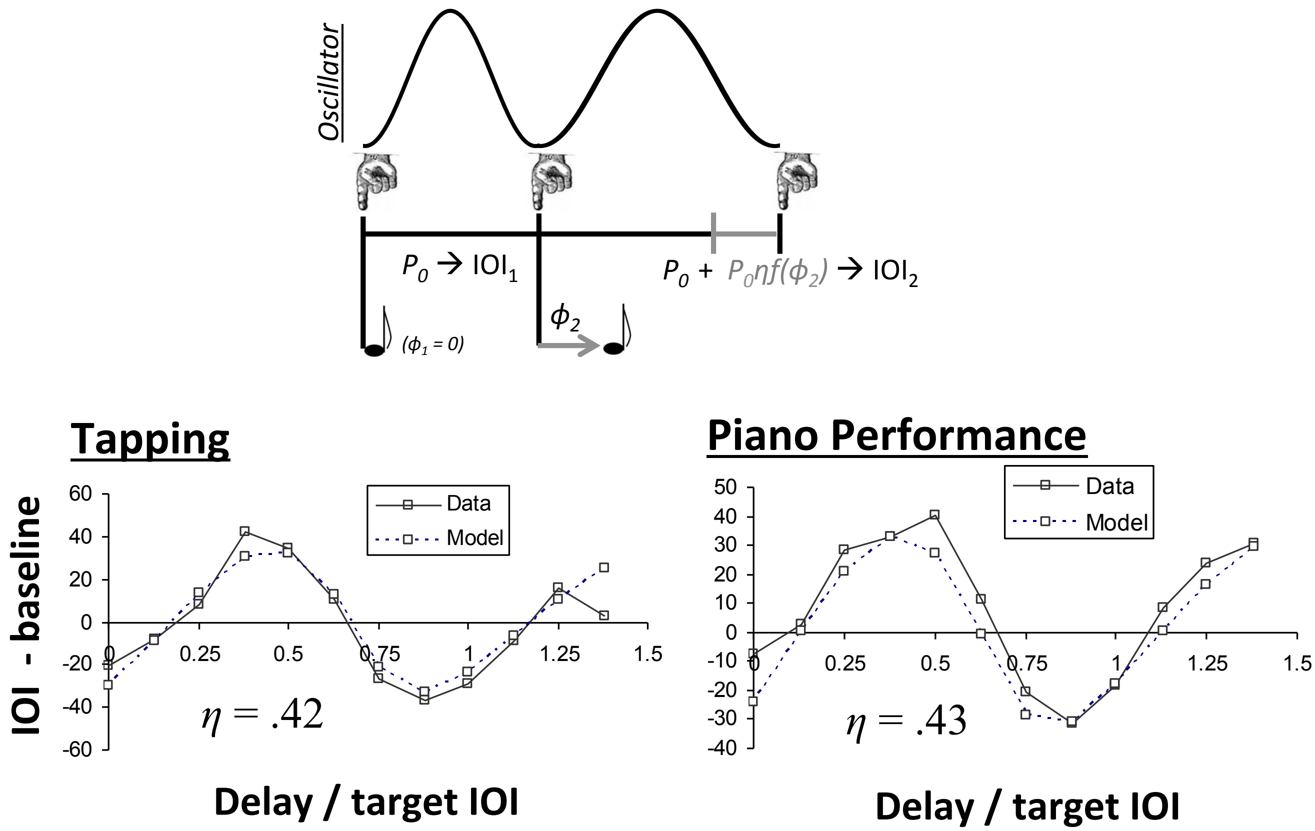


Figure 3.6: Phase perturbation caused by a single feedback asynchrony (cf. Equation 3.3). The vertical dimension is time, and the oscillator may reflect changes in finger height in space. The timing of auditory feedback is indicated by the note heads, and the effect of a delayed onset for the second IOI is shown by the addition of the grey vertical line to the base period of the oscillator. See the text for further details. Lower panels show fits of this model to performance data (Pfordresher, 2007).

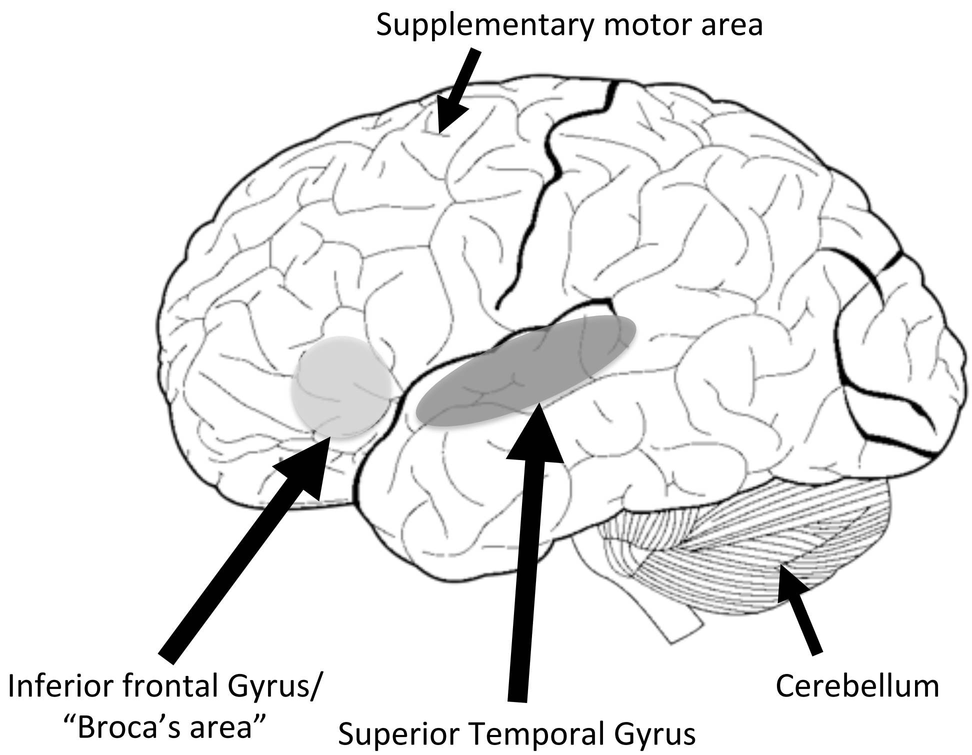


Figure 3.7: Approximate location of brain areas exhibiting larger responses during production with asynchronous auditory feedback than when production with normal feedback in music performance (Pfordresher et al., 2014) as well as in speech. Activation in the darker oval was corroborated in three different studies of speech (Hashimoto & Sakai, 2003; Takaso et al., 2010; Watkins et al., 2005), whereas activity in the lighter oval was only found in two speech studies (Hashimoto & Sakai, 2003; Watkins et al., 2005). Superior temporal gyrus activity was bilateral in all studies, whereas Inferior Frontal Gyrus activity varied in lateralization. Small arrows are used for areas specific to Pfordresher et al (2014) and, in the case of the cerebellum, only one speech study (Watkins et al., 2005).

CHAPTER 4

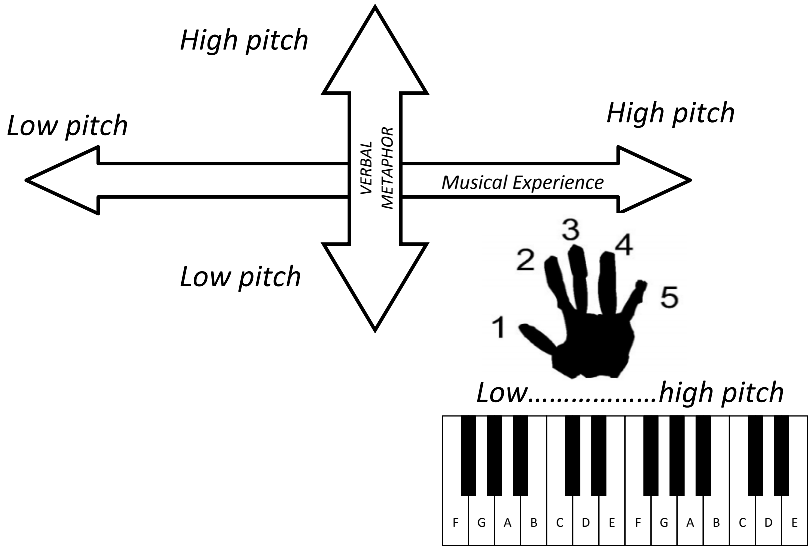


Figure 4.1: Associations between pitch and spatial locations based on experience.

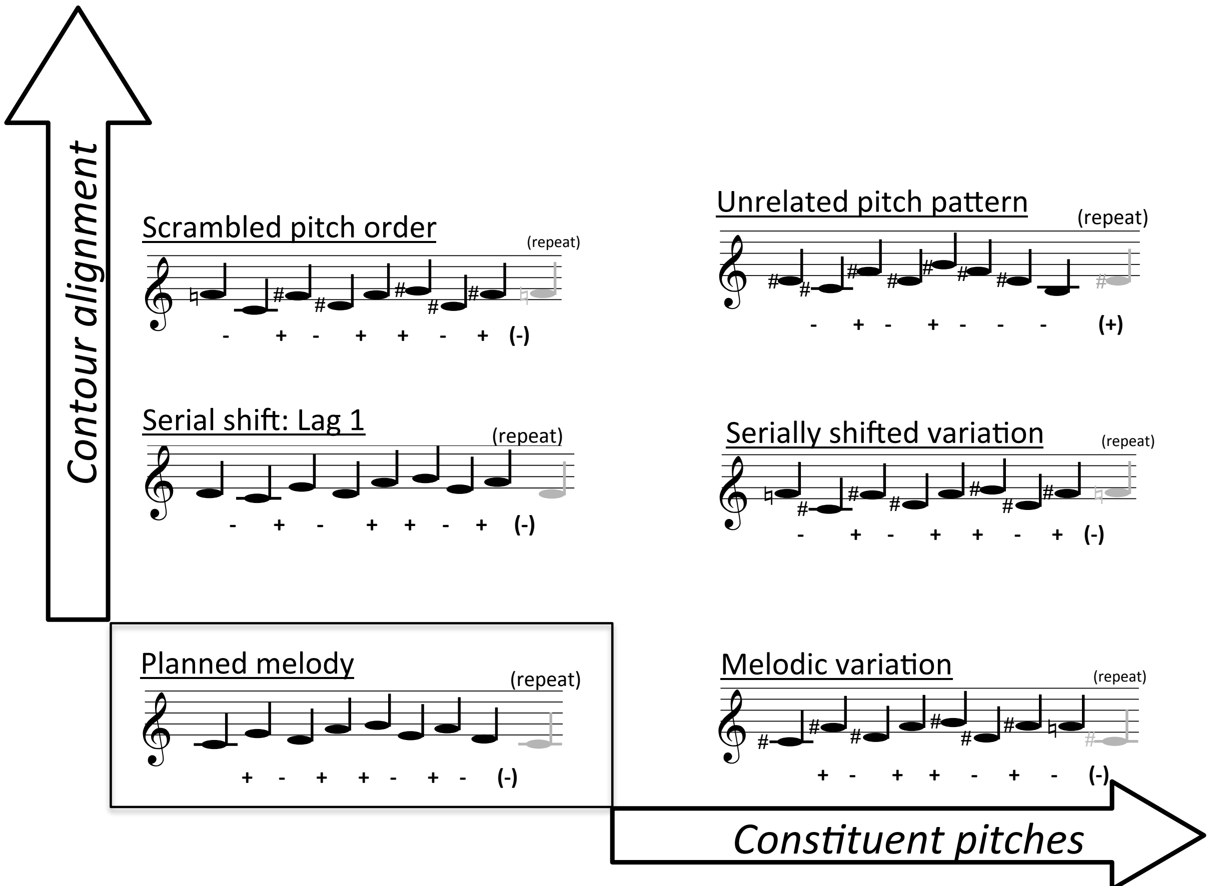


Figure 4.2: Examples of selected manipulations to feedback content, shown in music notation. One repetition of an example melody is shown, with grey notes at the end indicating the use of repeated cyclical performance. The melodic contour of each melody is shown below notation, with "+" indicating upwards pitch motion and "-" indicating downwards pitch motion. Alterations from the planned melody can be roughly distinguished based on alterations to the melodic contour pattern (vertical dimension), and matches of the constituent pitch events (horizontal).

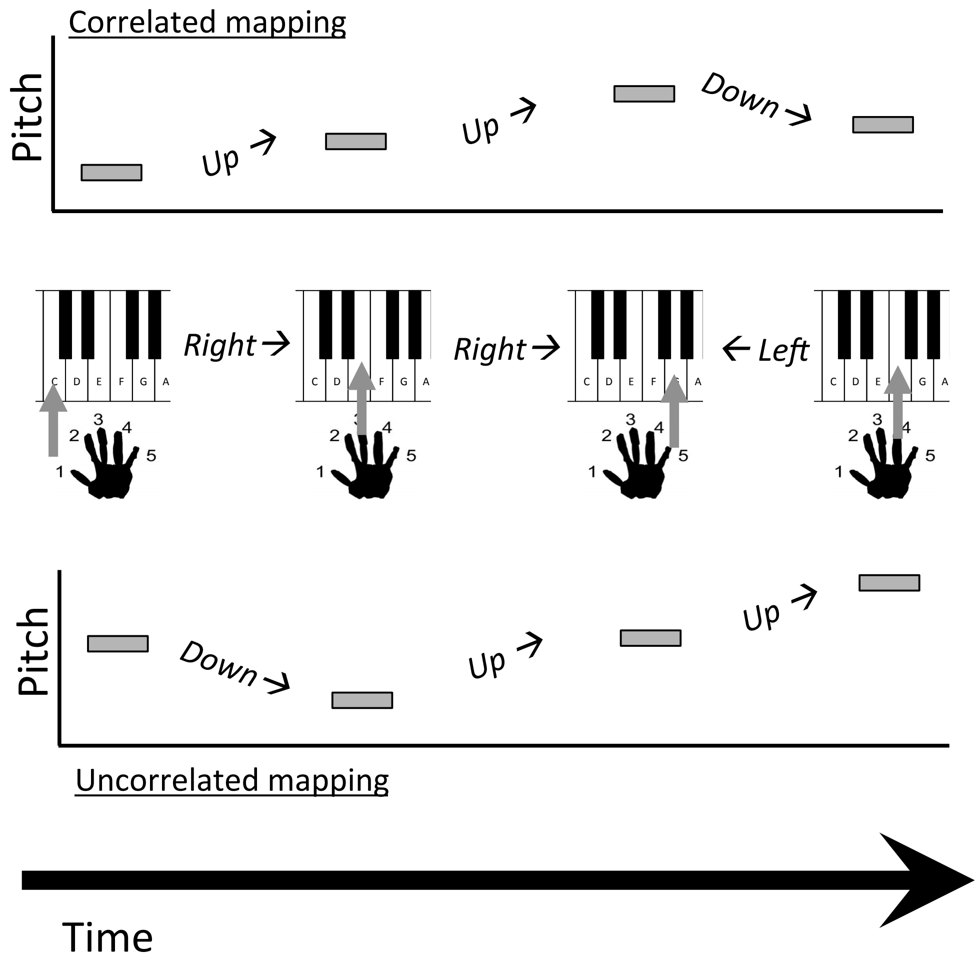


Figure 4.3: Schematic depiction of a sequence of keypresses on a piano over time (middle), and how these may lead to a feedback pitch sequence with changes in melodic contour that are correlated with movement (upper) or are not correlated with movement (lower). Auditory feedback is shown using "piano roll" notation in which rectangles stand for pitches that vary in time (x-axis) and pitch height (y-axis).

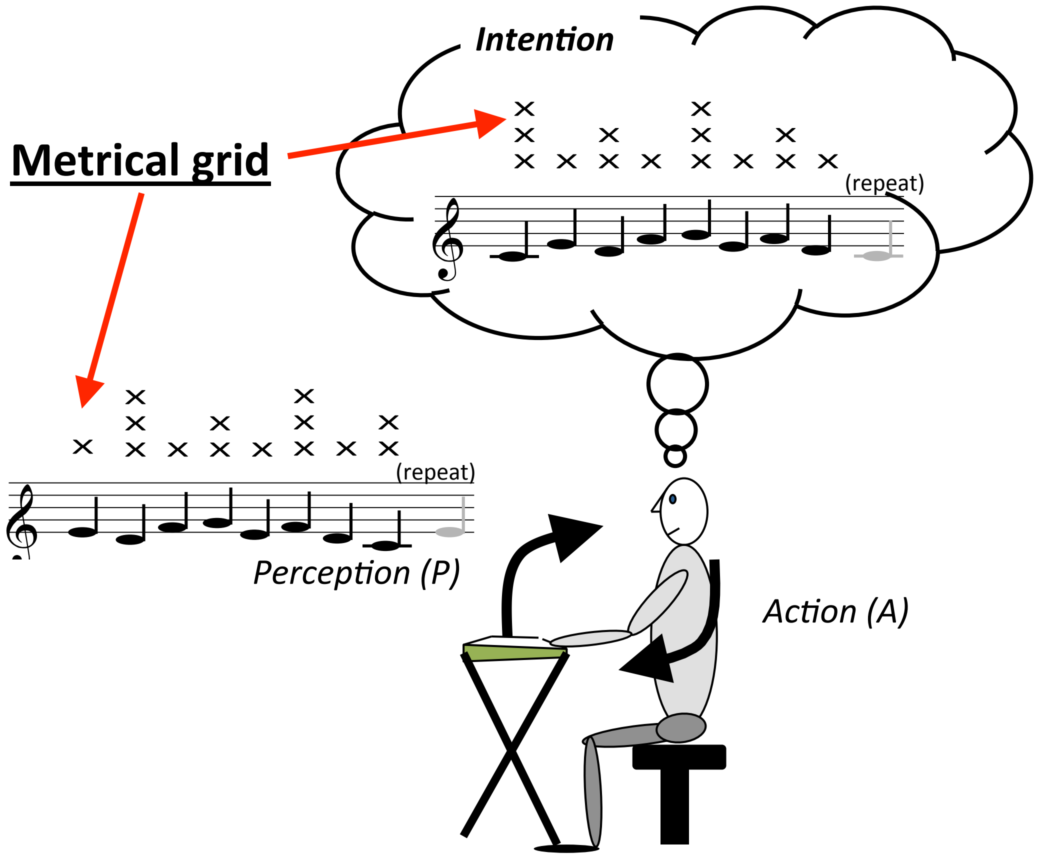


Figure 4.4: Illustration of metrical conflict caused by a lag-1 serial shift of auditory feedback. Notation for the planned melody (in the thought bubble) and auditory feedback are shown below metrical grids that represent alternating patterns of accent strength. Accented events fall beneath columns with more than one "x", with the strength of the accent proportional to the height of each column. Serially shifted feedback causes clashes between accents in the planned melody and accents in auditory feedback.

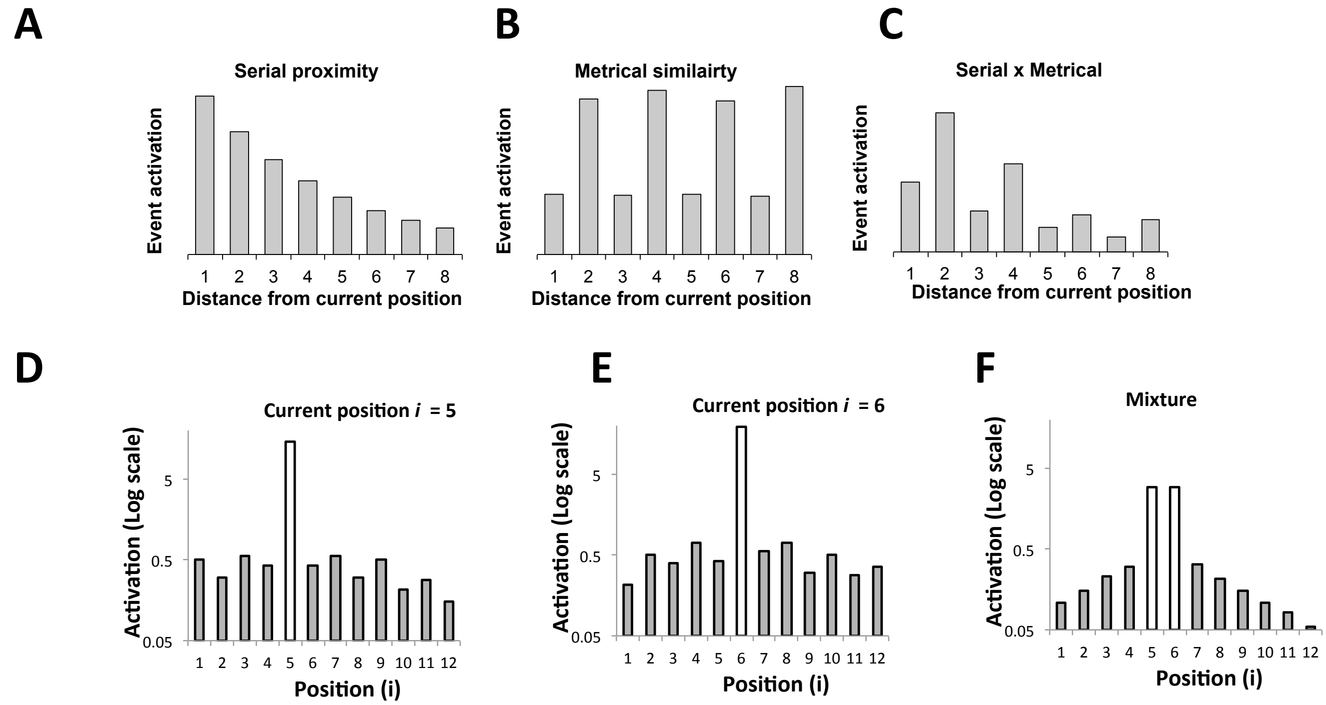


Figure 4.5: The range model of planning. A-C: Interaction of serial (A) and metrical (B) components, leading to predicted activations based on their product (C). D-F: Positional uncertainty resulting from a serial shift in which the activation gradient associated with auditory feedback (D) lags one position behind the planned current event (E), leading to a combined gradient that poorly disambiguates the correct event from surrounding events (F).

CHAPTER 5

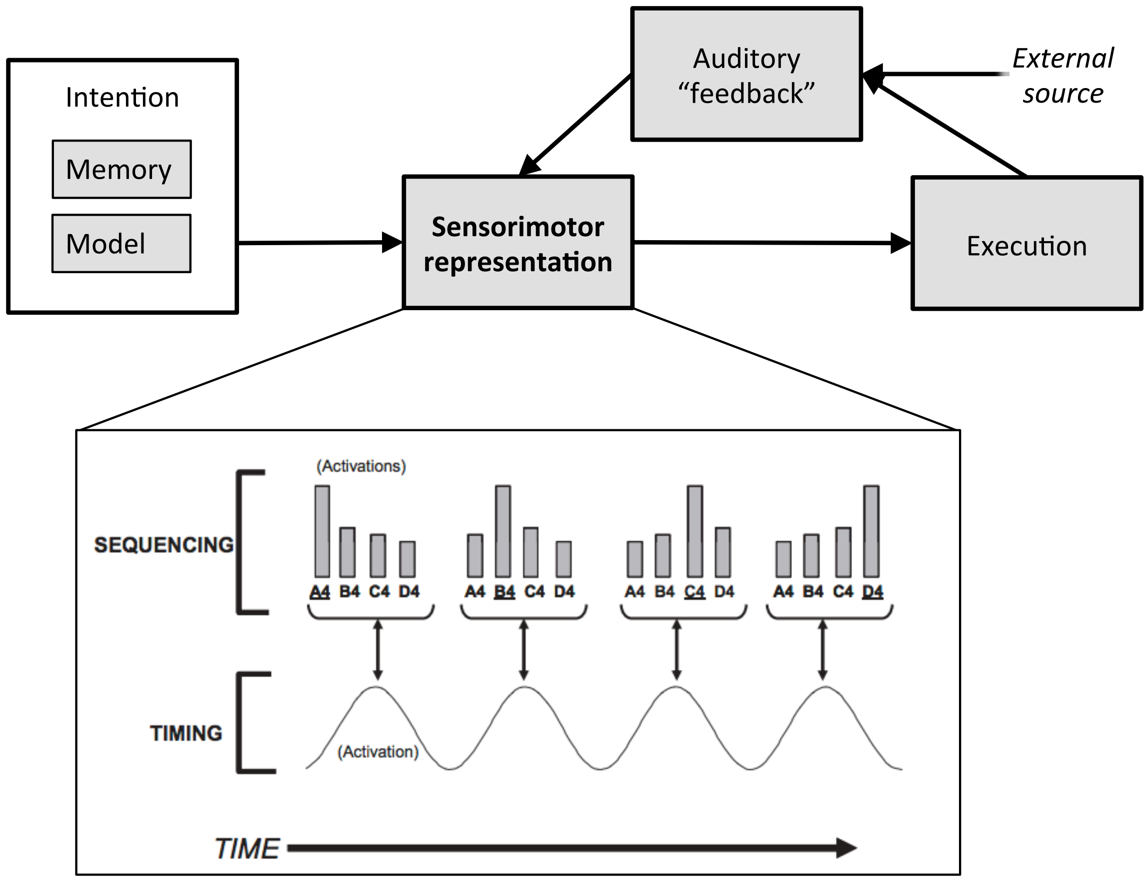


Figure 5.1: The sensorimotor loop relating perception to action, including the hierarchical structure of the sensorimotor representation (based on Pfordrsher & Kulpa, 2011).

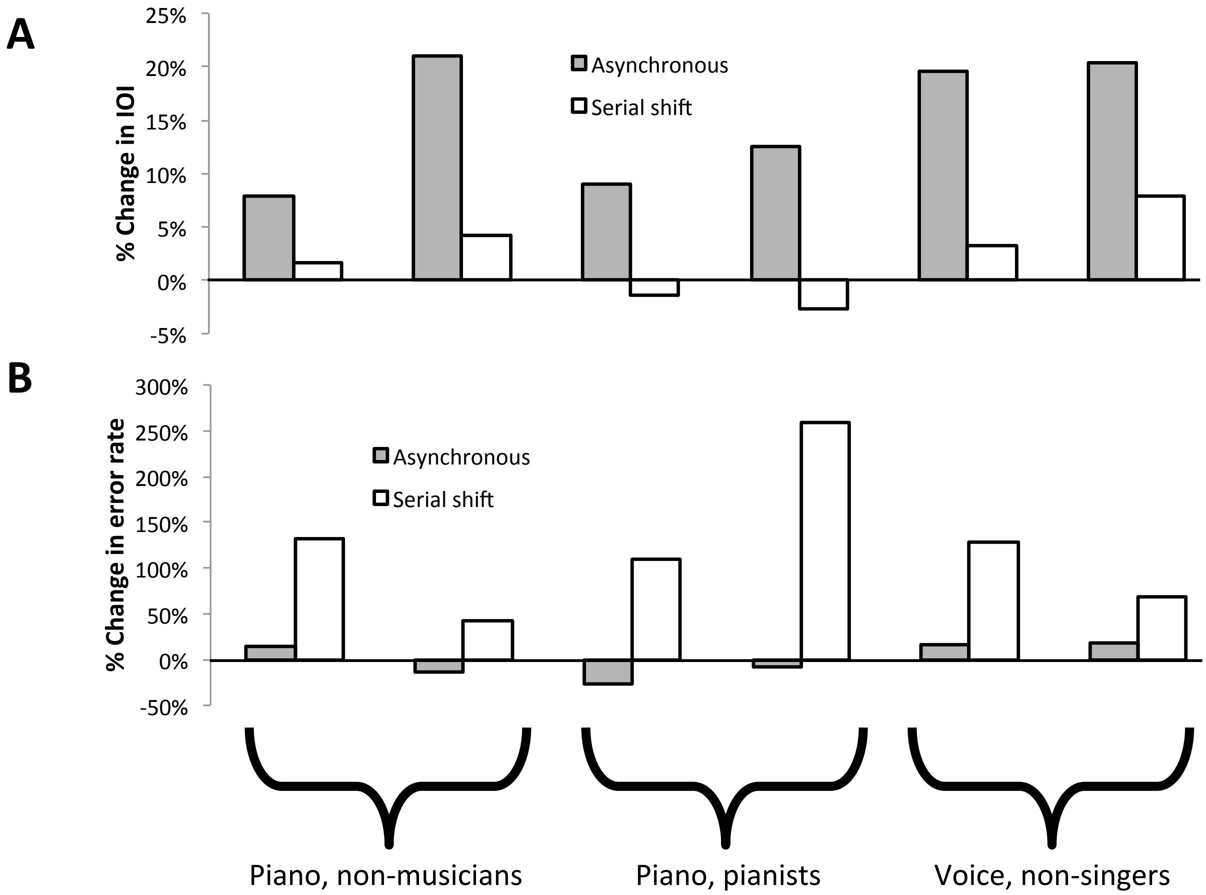


Figure 5.2: Summarized results from studies measuring effects of asynchronous (A) versus serially shifted (B) auditory feedback within-subjects. Y-axes represent differences between altered and normal feedback conditions, relative to performance in the normal condition. From left to right, data sets are: Couchman et al., 2012, Experiment 1; Pfordresher & Mantell, 2012, keyboard trials; Pfordresher et al., 2015; Pfordresher, 2003, Experiment 4; Pfordresher & Mantell, 2012, singing trials; Pruitt & Pfordresher, 2015, singing trials.

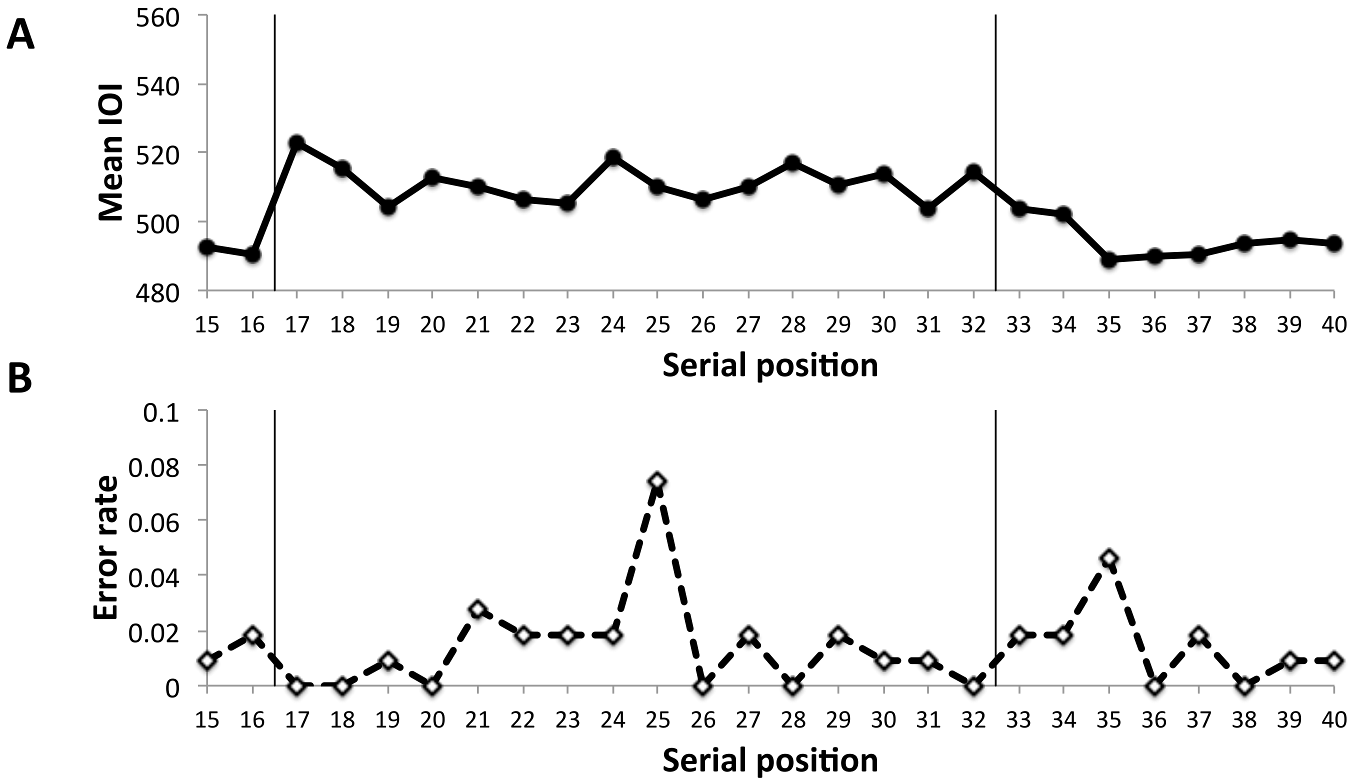


Figure 5.3: The time course of disruption from asynchronous feedback (A) and serially shifted feedback (B). Data from Pfordresher and Kulpa (2011). In each panel, vertical guides delineate a sequence of tones for which auditory feedback was altered. Events before and after this region were associated with normal auditory feedback. Each data point is an average across participants. The first 16 events of the trial functioned as a baseline; only the last two events from this phase are shown as reference points against which to judge the effect of alterations.

CHAPTER 6

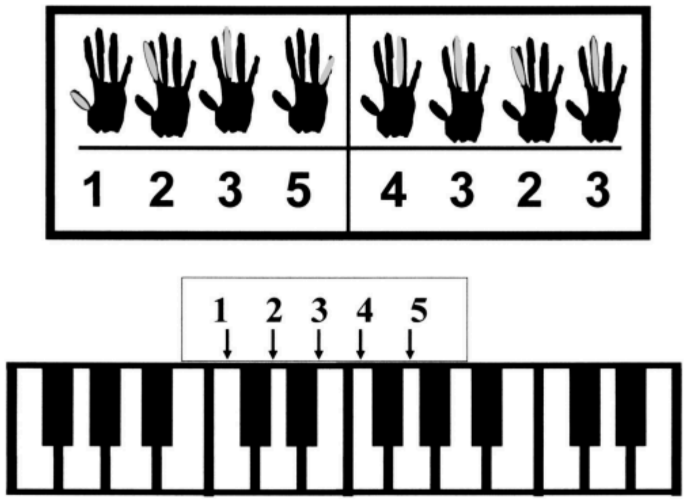


Figure 6.1: Notation system used for non-pianists (reprinted from Pfordresher, 2005).

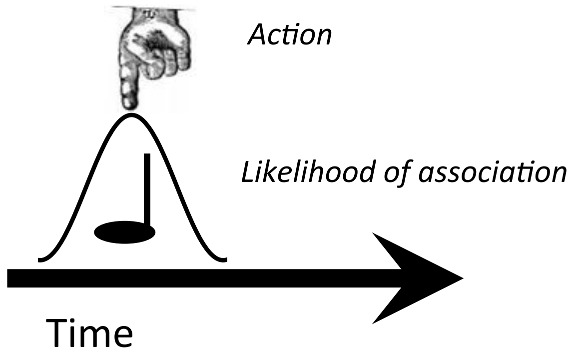


Figure 6.2: Temporal synchrony constraint on sensorimotor learning.

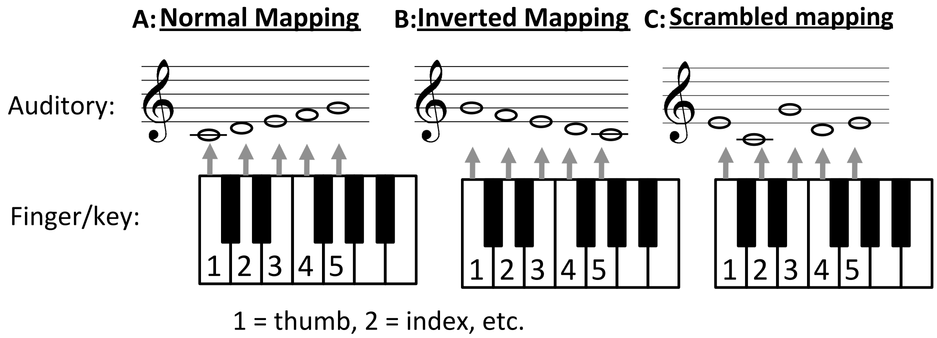


Figure 6.3: Examples of how mapping from piano keys (and fingers) to pitch may be manipulated.

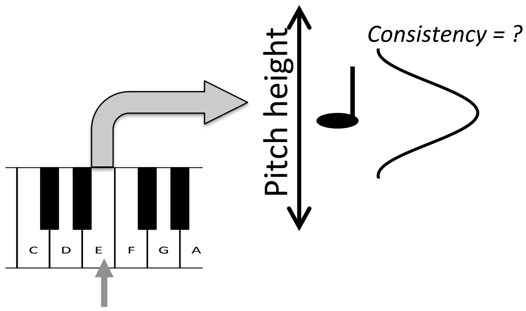


Figure 6.4: Reliability constraint on sensorimotor learning.

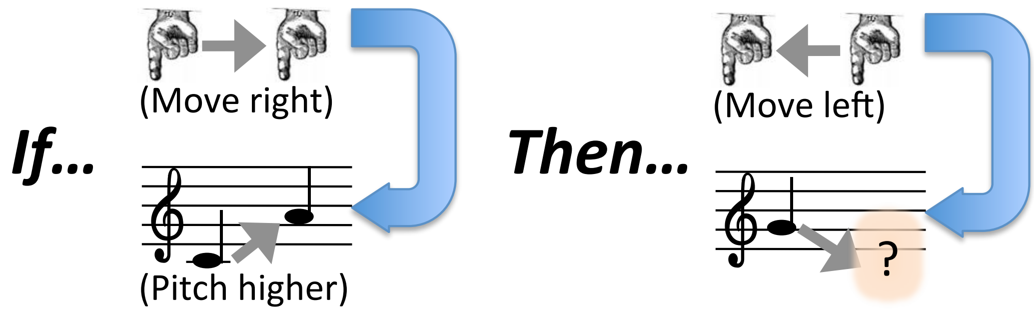


Figure 6.5: Directionality constraint on sensorimotor learning

Figure 6.6: Proportionality constraint on sensorimotor learning

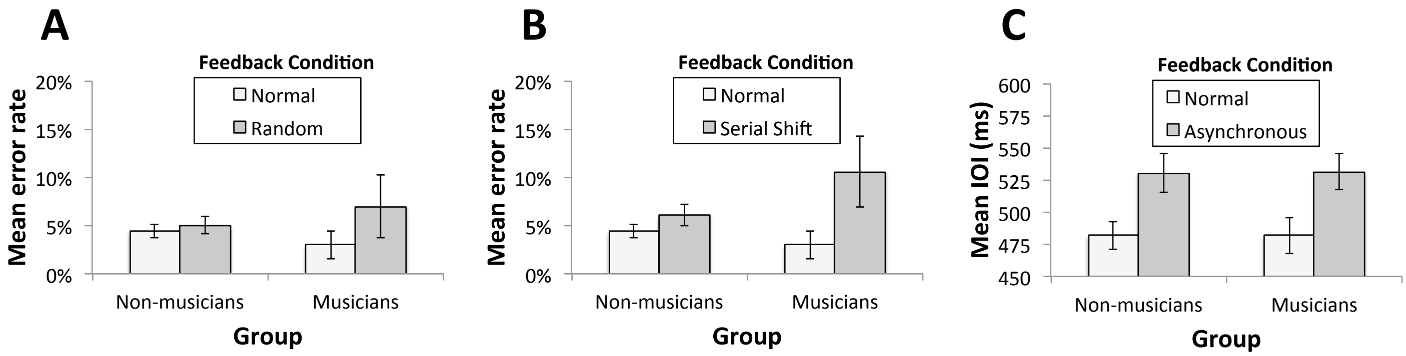


Figure 6.7: Effect of musical training on disruption from alteration of feedback pitch content based on randomly selected pitches (A) or a lag-1 serial shift (B), based on pooled data from Pfordresher (2005). By contrast, training has no effect on the effect of feedback synchrony (C), based on pooling data from several other studies. Error bars represent 95% confidence intervals.

CHAPTER 7

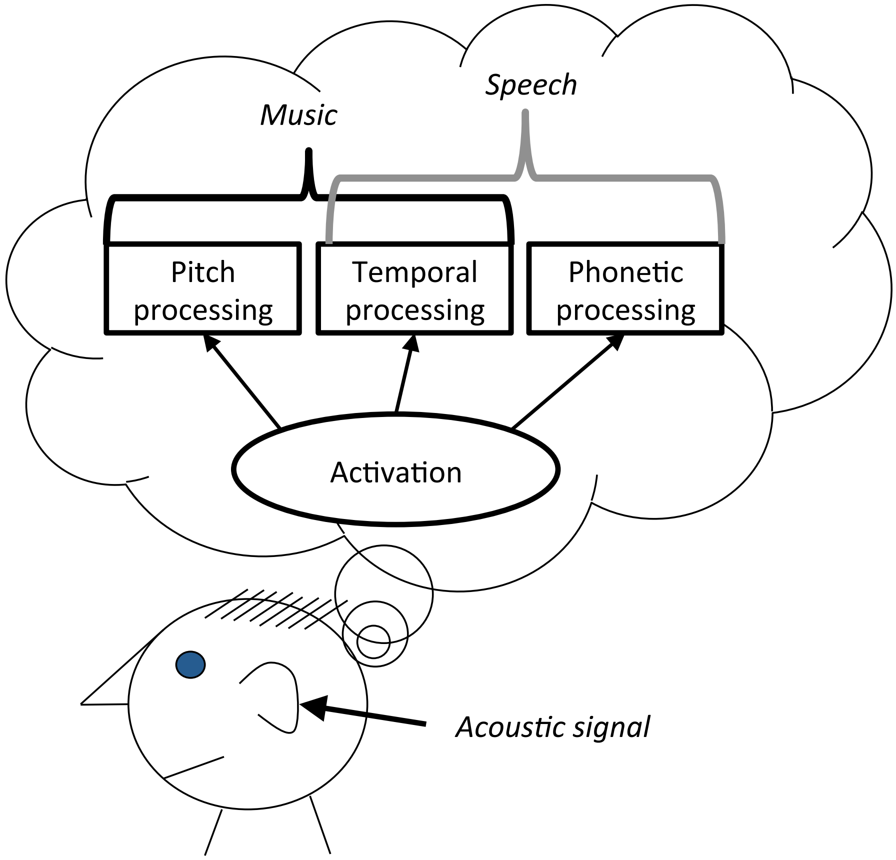


Figure 7.1: A highly simplified illustration of music and language processing that integrates two leading approaches. Different functional modules for music and language (e.g., Peretz & Coltheart, 2003) are represented by boxes within the thought bubble. The functioning of each module may be governed by a shared resource for activation (e.g., Patel, 2008), shown below the modules.

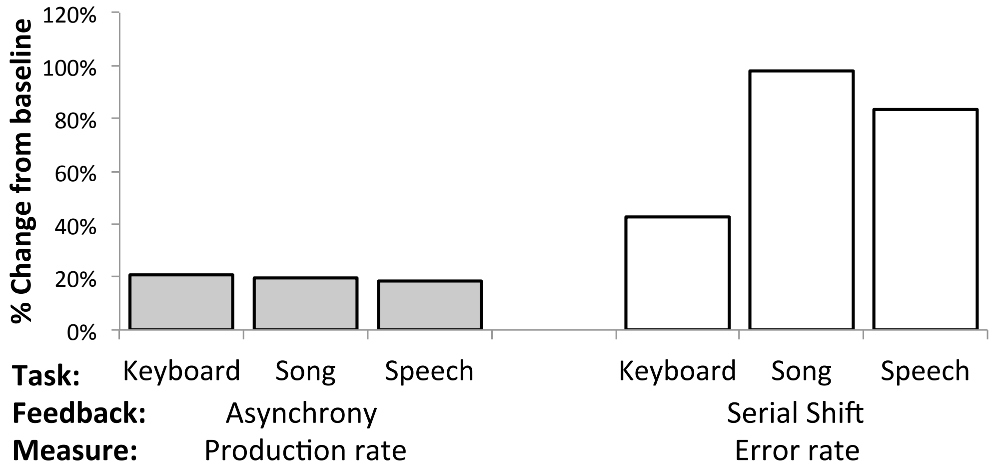
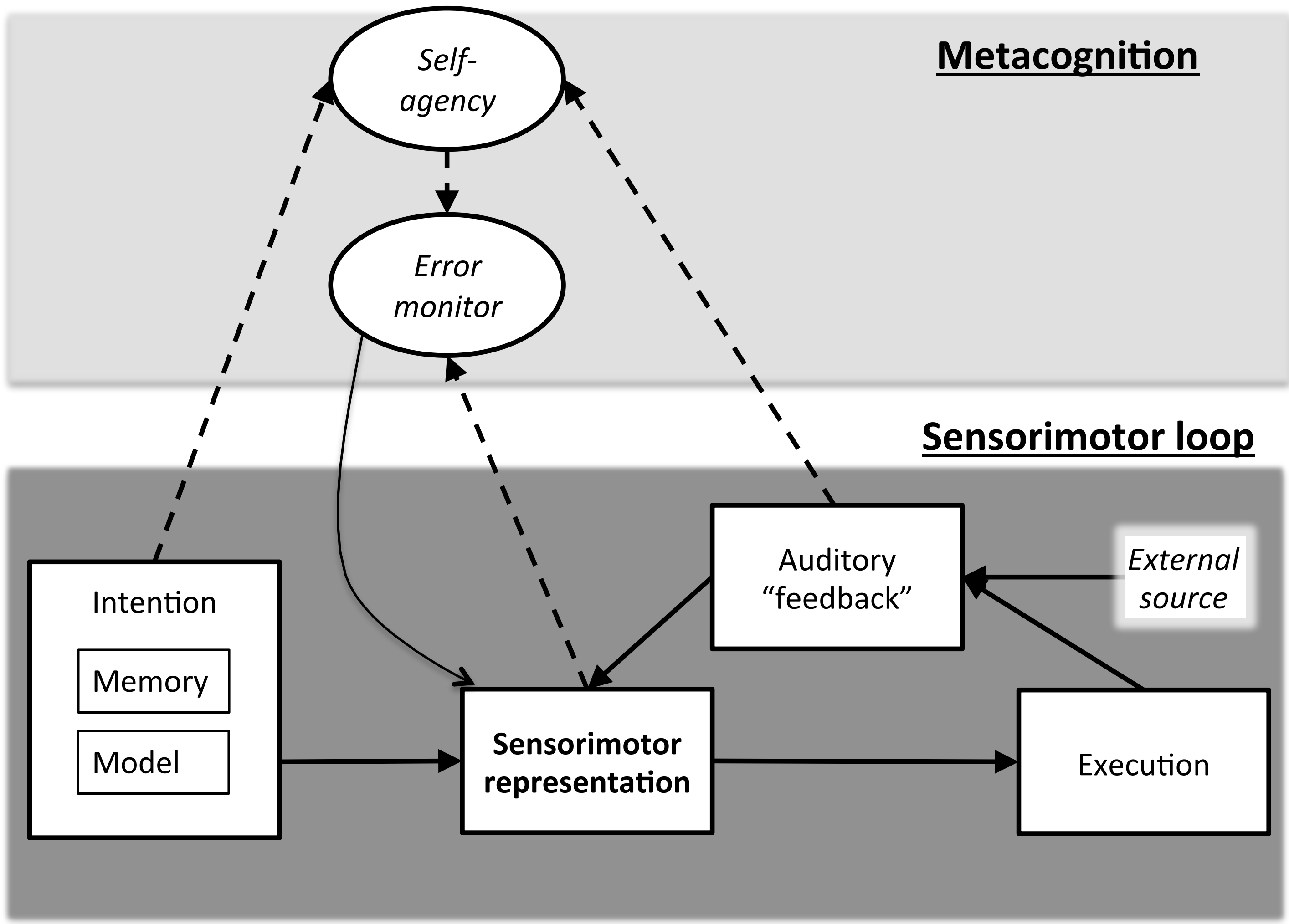


Figure 7.2: Comparison of several studies that involve manipulations of feedback synchrony or content, for music and speech production tasks. See the text for further details.

CHAPTE8



Metacognition
Self-agency
Error monitor
Sensorimotor loop
Auditory "feedback"
External source
Intention
Memory
Model
Sensorimotor representation
Execution

CHAPTER 9

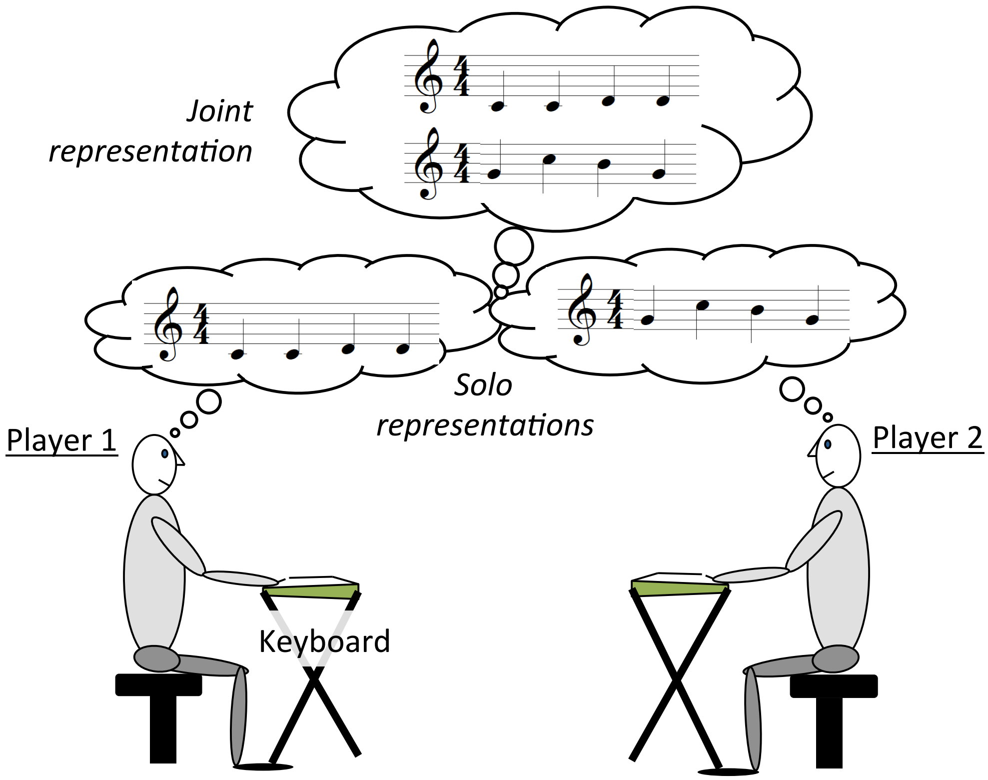


Figure 9.1: Cartoon of solo versus joint representations in a piano duet performance

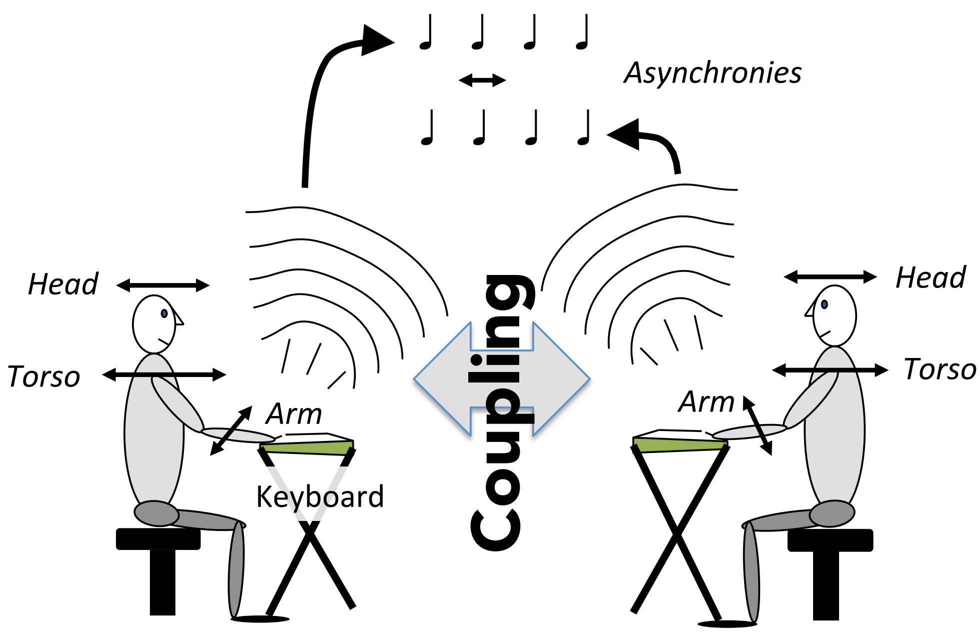


Figure 9.2: Cartoon illustrating patterns of coupling in entrainment. Salient rhythmic body movements are highlighted using double-sided arrows. Sound is represented as an acoustic stimulus from each keyboard using wave patterns, and as a perceptual representation via notation above the performers. Coupling may occur across any form of movement, or feature of the sound pattern, as represented by the double-sided arrow in the center.