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Effects of meter and serial position on memory retrieval during music performance

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Effects of musical meter on memory retrieval in music performance were investigated. The range model, a formal model of memory retrieval in music performance, proposes that metrical similarity influences retrieval during sequence production. This assumption was tested by examining production errors in skilled pianists' performances of novel musical pieces. Pieces were practiced to a note-perfect criterion and subsequently performed at fast and medium musical tempi. The relative metrical accent strength of musical events influenced error rates. Effects of metrical accent on accuracy interacted with production rate; performance of metrically weak events was affected by tempo, but performance of the most strongly accented events was not. These findings indicate influences of higher-order event relationships on memory retrieval during production, consistent with theories of expert memory in music performance.

Keywords: music performance; musical meter; serial position; production errors; memory retrieval

Expert musicians produce complex auditory sequences with noteworthy precision. Long and technically difficult musical works can be performed from memory with low error rates (Finney and Palmer 2003). Although previous work has investigated the role of serial position of sequence events in performance accuracy (Mishra 2010), fewer studies have investigated the role of metrical structure, which may influence the memory encoding and retrieval of musical sequences (Palmer and Krumhansl 1990).

The range model of memory retrieval in music performance (Palmer and Pfordresher 2003, Pfordresher *et al.* 2007) proposes that metrical accents determine similarity relationships among events that affect retrieval. As a test

of this assumption, we investigated effects of metrical accent strength and sequence position on pitch error rates in piano performance. Error rates at two performance tempi were compared to examine interactions of serial position and metrical relationships with the speed-accuracy tradeoff typically seen in music performance (Palmer and Pfordresher 2003, Pfordresher *et al.* 2007), which predicts that faster speeds yield higher error rates.

METHOD

Participants

Twenty-six adult pianists from the Montreal community (mean age=22.9 years) participated in the study. Participants had between 7 and 29 years of piano experience (mean=15.8). All participants reported playing the instrument regularly; none reported any hearing problems.

Materials

Eight musical pieces were composed for the experiment. Each piece consisted of 33 events, where an event was defined as a single or set of notated pitches to be performed simultaneously. All musical pieces were notated with the same time signature ($^4/_4$) and were isochronous; 32 sixteenth-note events followed by a whole note were scored for both hands. The composed pieces were novel and technically difficult, and short enough to be learned in a single experimental session. Pieces conformed to Western polyphonic music conventions (e.g. no parallel fifths or octaves between voices).

Procedure

At the start of the session, participants practiced the pieces until an error-free performance was achieved at a slow tempo (429 ms per sixteenth-note interonset interval [IOI] indicated by a ticking metronome). This criterion ensured that errors occurring at faster tempi were not due to sight-reading failures, errors of perception, or incorrect learning of the musical pieces.

Following practice, participants performed each of four pieces twice per block over four experimental blocks, with the musical notation in view. Two pieces were always performed at a medium tempo (225 ms per sixteenth-note IOI), and the other two always at a fast tempo (187.5 ms per sixteenth-note IOI). Tempo was established by metronome ticks at the quarter-note level. Additional unrelated pieces were performed either before or after the performances of the pieces evaluated in the study. Piece ordering and assignment of tempo to piece were counterbalanced. Thus, the design was a re-

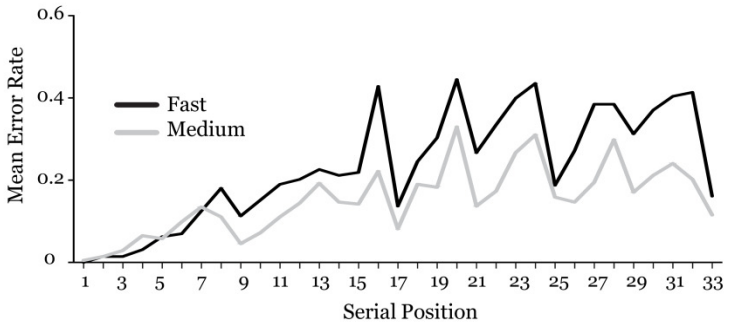

Figure 1. Mean error rates at fast and medium tempi by serial position.

peated measures design with 2 (performances) x 4 (blocks) x 2 (tempi). Pianists were instructed to perform at the tempo indicated by the metronome throughout the trial and to perform without correcting any errors.

RESULTS

Participants produced 5,131 errors across all sequences. The mean error rate per single performance was 0.11. Mean produced IOIs were 194 ms in the fast condition (compared with the prescribed 187.5 ms) and 227 ms in the medium condition (compared with the prescribed 225 ms). Figure 1 shows the mean error rates by sequence position and tempo.

A 2 (tempo) x 33 (serial position) repeated measures analysis of variance (ANOVA) on error rates indicated a significant main effect of tempo ($F_{1,25}$=15.18, p<0.01). Error rates at the fast tempo (mean=0.23) were significantly higher than error rates at the medium tempo (mean=0.15), consistent with speed-accuracy tradeoffs in performance. There was a significant effect of serial position on error rates ($F_{32,800}$=19.58, p<0.001). Also, there was a significant interaction of tempo with serial position ($F_{32,800}$=2.39, p<0.001), indicating that the effect of tempo on errors was modulated by sequence position. Mean error rates in Figure 1 indicate a strong primacy effect at both performance tempi, with highest accuracy for events at the beginning of the sequence, and a smaller recency effect.

Peaks in Figure 1 also suggest that higher error rates aligned with metrically weak positions (upbeats) and lower error rates with metrically strong positions (downbeats). To examine the effect of metrical strength on error rates, each event in the sequence was coded for metrical accent strength according to a 4-tier metrical grid consistent with the time signature and small-

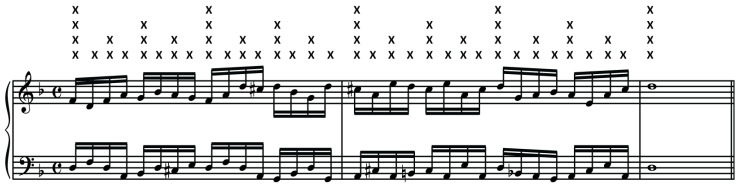

Figure 2. One of the notated stimulus pieces with metrical accent strengths according to a 4-tier metrical grid. Events aligned with all tiers are most strongly accented.

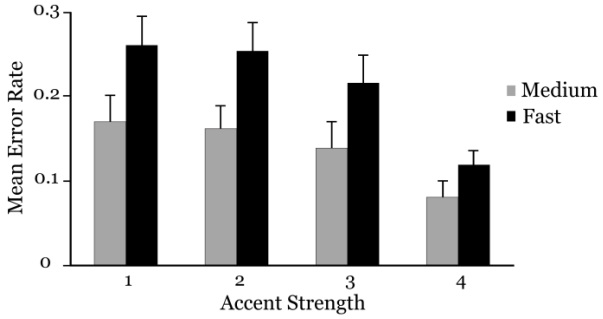

Figure 3. Mean error rate as a function of metrical accent strength and tempo.

est notated duration in the score, as shown in Figure 2 (Lerdahl and Jackendoff 1983).

A 2 (tempo) x 4 (accent strength, 1-4) repeated measures ANOVA on error rates revealed a significant main effect of metrical accent strength ($F_{3,75}$=24.84, p<0.01). As shown in Figure 3, events aligned with more tiers of the metrical hierarchy had lower error rates. Post-hoc comparisons (Tukey HSD=0.0418, α=0.05) indicated that mean error rates for events accented at level 4 were significantly lower than error rates of events accented at levels 1, 2, and 3. Mean error rates corresponding to accent strengths 1, 2, and 3 did not significantly differ from one another. On average, events aligned with the strongest metrical accents were performed most accurately. There was also a significant main effect of tempo ($F_{1,25}$=15.47, p<0.01), and a significant tempo x metrical accent interaction ($F_{3,75}$=3.37, p<0.05). The medium tempo generated lower error rates than the fast tempo, consistent with a speed-accuracy tradeoff, and metrical accent strength modulated the size of that tradeoff.

Figure 3 suggests that the influence of tempo was reduced for events aligned with the strongest metrical accent (level 4). Posthoc comparisons (Tukey HSD=0.0515, α=0.05) of the tempo x accent strength interaction con-

firmed that faster tempi generated higher error rates than medium tempi at positions with accent strengths 1, 2, and 3, but not at tier 4. Musical events with greater metrical accent strength were more resistant to error at both tempi.

Both primacy effects and increased metrical accent may make musical events less susceptible to error. Correlations between mean error rates and metrical accent strengths, after the effects of serial position were removed from the error rates (regressing metrical accent on the residuals of error rates), were significant and negative for both the fast condition ($r=-0.55$, $p<0.01$) and the medium condition ($r=-0.50$, $p<0.01$). Thus, error rates decreased as metrical accent strength increased, above and beyond the effects of serial position.

DISCUSSION

Accuracy of music performance was influenced by the serial position and metrical accent strength of events. Primacy effects enhanced performance of events at the beginnings of sequences, and meter enhanced performance of events in metrically strong positions. These findings are consistent with the general finding that the perceived salience of meter takes time to be established (Longuet-Higgins and Lee 1982). Accent strength modulated the effects of the speed-accuracy tradeoff; metrically accented events were resistant to effects of increased tempo that usually yielded higher error rates. This finding extends previous work that documented serial position effects across a musical piece (Mishra 2010), based on error rates averaged across metrical positions. The current study's novel focus on the contributions of metrical position to retrieval accuracy indicated that hierarchical metrical relationships transformed classic serial influences by boosting memory retrieval for accented events during production.

Memory retrieval during music performance may be simultaneously influenced by both short-term retrieval constraints and long-term knowledge of musical event relationships. This approach is taken by the range model of memory retrieval in music performance (Palmer and Pfordresher 2003, Pfordresher *et al.* 2007), which assumes long-term influences of metrical accent hierarchies on the types of errors made by performers during production. The current findings support this assumption and are consistent with theories of expert memory in music performance (Ericsson and Kintsch 1995), which propose that well-learned hierarchical frameworks provide skilled musicians with a means of quickly and accurately retrieving information from memory.

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