ARTICLE TEMPLATE

Beat and Switch: Multi-stable Metre, Metric Fake-outs, and the Strong-Beat-Early rule

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ABSTRACT

This paper presents the first dedicated study of a widely attested metric phenomena, dubbed by London the metric *fake-out*. Metric fake-outs are byproducts of metric ambiguity in the opening moments of a musical piece. This paper reviews relevant literature regarding metric ambiguity, defines and classifies metric fake-outs, and presents the results of three simple empirical studies of fake-out passages: The first exploratory study attempts to estimate the prevalence of metric ambiguity, and fake-outs in particular, in popular music. Results suggest that approximately one in fifteen commercially successful popular songs evokes at least fleeting metric ambiguity, while one in approximately sixty contains a definite metric fake-out. A second exploratory study documents the varying metric interpretations of seventeen musicians listening to excerpts popular and classical music which feature fake-outs. This data is used as a jumping off point for theoretical discussions of metric preference rules of the twenty-four passages. This discussion calls attention to the importance of the initial rhythmic onsets in shaping metric perception, a role roughly recognized by Lerdahl and Jackendoff's (1983, p. 76) 'Strong Beat Early' preference rule. A final experimental study formally tests the contribution of the 'Strong Beat Early' preference rule by presenting participants with edited versions of a subset of the excerpts from Study 2. Results are consistent with the hypothesis that listeners strongly assume that the first heard onset is a strong beat.

KEYWORDS
Metric Induction; Rhythm; Ambiguity; Popular music

1. Introduction

Rhythm in most music is organized in relation to *metre*: a hierarchy of regular beats (London, 2004; Fitch & Rosenfeld, 2007, p. 43). Metre provides an 'anticipatory schema' (London, 2004, p. 12) which guides listeners' expectations regarding the timing of musical events (Fitch, 2013, p. 3), including non-adjacent events (Drake, Jones, & Baruch, 2000, p. 2). However, metre is not explicitly articulated in musical sound; rather, listeners must infer metre from music (London, 2004; Fitch & Rosenfeld, 2007, p. 44; Fitch, 2013, p. 2). The inferred metre greatly influences how music is perceived (Acevedo, Temperley, & Pfordresher, 2014; London, 2004; Temperley, 2001), such that different interpretations of identical stimuli are often not recognized as being the same

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(Povel & Essens, 1985, p. 432; Sloboda, 1985, p. 275; Palmer & Krumhansl, 1990, pp. 736–738). The experience of rhythm in music is thus governed by a dynamic balance between metric *recognition*—extracting metre from music—and metric *continuation*—'actively projecting a pattern of beats and measures... onto the music' (London, 2004, p. 53).

Metre recognition has been an active topic in music psychology for decades.[1] Much music theoretic work has focused on rule-based models of metric recognition, notably the influential *preference rule* model of Lerdahl and Jackendoff (Lerdahl & Jackendoff, 1983; London, 2004; Temperley, 2001). One simple over-arching generalization underlies most such rules: the preference to associate stronger metric positions with more salient musical events.[2] From a psychological perspective, it is unlikely that the brain literally applies discrete rules to infer metre, instead drawing upon more diffuse *implicit knowledge* regarding abstract statistical regularities (Huron & Ommen, 2006; Palmer & Krumhansl, 1990). Still, preference rules offer a simple, convenient, and parsimonious framework for summarizing the implicit knowledge of enculturated listeners, and will be used throughout this paper.

Metric Ambiguity

Any musical rhythm can potentially heard in relation to numerous metric hierarchies (Longuet-Higgins & Lee, 1984; Fitch, 2013, p. 4). London (2004) refers to this potential as *metric malleability*. The metric malleability of musical rhythm raises the possibility of ambiguity regarding the metre of any musical passage. Metric ambiguity is analogous to the broader phenomenon of *multi-stability* (Karpinsky, 2012).[3] Famous multi-stable images include the Necker Cube, Rubin's Vase, and Spinning Dancer illusion. Multi-stability occurs when the perceptual inference process cannot decide between interpretations: An important property of multi-stable ambiguity is that interpretations are mutually exclusive: one cannot see the Spinning Dancer spinning clockwise and counterclockwise at the same time. Scholars largely agree that metric interpretations are similarly mutually exclusive—i.e. one cannot experience a rhythm in two metres simultaneously (London, 2004; Smith, 2006, pp. 59–60; Karpinsky, 2012). Whether the 'latent ambiguity' (London, 2004) of musical metre ever leads to truly ambiguous experiences is somewhat contentious. Agawu (1994, pp. 89,103) argues that music is never truly 'metrically undecidable,' as different interpretations are never 'comparably or equally plausible.' According to Agawu, 'while ambiguity may exist as an abstract phenomena, it does not exist in concrete musical situations' (1994, p. 107).

Most models of metric inference take music notation as input. Notation encodes musical rhythms as categorical durations, defined not by absolute length but relative to each other in terms of simple integer ratios. These abstract representations of rhythm provide relatively little information from which to identify metre, and are thus metrically malleable. However, musical performances feature significant variability in actual timing compared to these abstract representations[4]—some systematic

[1] Desain, 1992; Longuet-Higgins & Lee, 1982, 1984; Povel & Essens, 1985; Rosenthal, 1992; Parncutt, 1994, pp. 423–442; Large & Palmer, 2002; London, 2004.

[2] Most metric recognition models have focused on common-practice era European art music. Metric rules may differ in other genres, such as American popular music (Temperley, 2001).

[3] It should be kept in mind that multi-stability, and ambiguity more broadly, is not the same as *vagueness* (London, 2012, p. 106). Ambiguity involves a choice between a small number of concrete possibilities, whereas vagueness means no clear interpretation is evident (Agawu, 1994, p. 90; Karpinsky, 2012).

[4] (Benadon, 2006; Davies, Madison, Silva, & Gouyon, 2013; Fruhauf, Kopiez, & Platz, 2013; London, 2004;

and some stochastic (Hellmer & Madison, 2015). These rhythmic nuances form a *subsyntactic* dimension of rhythm, complementing the syntactic dimension represented by music notation (Prögler, 1995). Systematic manipulations of subsyntactic timing provides rhythmic cues which clarify metric structure.[5] According to London (2004, p. 100), 'The use of expressive variations of timing and dynamics will usually serve to disambiguate [the metre],' despite the metric malleability of the rhythm. Empirical studies have generally supported this claim, but results have been somewhat mixed. Sloboda (1983) conducted an empirical study of pianists' ability to convey metric interpretations using systematic variation in timing and dynamics: Pianists performed unaccompanied melodies with different interpretations of the phase of the metre—one version interpreted the first note as a pick-up while the other version interpreted the same note as the downbeat. A separate group of musically literate participants listened to these performances and selected which metric interpretation was being performed. The most skilled pianists were indeed able to communicate their intended metre to these listeners at a rate better than chance. However, performing better than chance is a somewhat modest achievement. The score achieved by Sloboda's most successful performer was only 221 out of a possible 300, with a score of 150 representing a pure chance performance. Sloboda's other performers—who were less experienced, but still far from amateurs—scored less than 200 (1983, pp. 390–392).[6] Gabrielsson (1973, pp. 144–145) indirectly observed a similar result: In his second and third experiments, a professional pianist performed syntactically identical rhythmic patterns with different metric interpretations—as in Sloboda's experiment, either interpreting the first note as a pick-up or a downbeat. Participants consistently heard the performances which were indented to be metrically distinct as the same.[7] Similar failures of metric communication have been observed in a variety of studies: Vos et al. (1981) observed ambiguity in the downbeat interpretation of listeners hearing Bach Preludes; Parncutt (1994, pp. 418–419) found that listeners interpreted simple rhythms with a variety of metric phases[8]; Drake et al. (2000, pp. 12–15) found that expressive timing prompted musicians to entrain to relatively high metric levels (though the effect was weak) but were unable to show that expressive timing improved accuracy of metric induction—in fact, the data was skewed in the opposite direction. These variety of observations suggest that performers are not always able to communicate the intended metre, raising the spectre (or the promise?) of metric ambiguity in real music.

Metric Fake-outs

This paper explores a particular musical effect which results from metric malleability, what London (2006) has dubbed the *metric fake-out*. Figure 1 illustrates a metric fake-out in the opening seconds of the song *Wake Up* (1984) by XTC. In the first four

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Penel & Drake, 1998; Prögler, 1995; Sloboda, 1983, 1985).

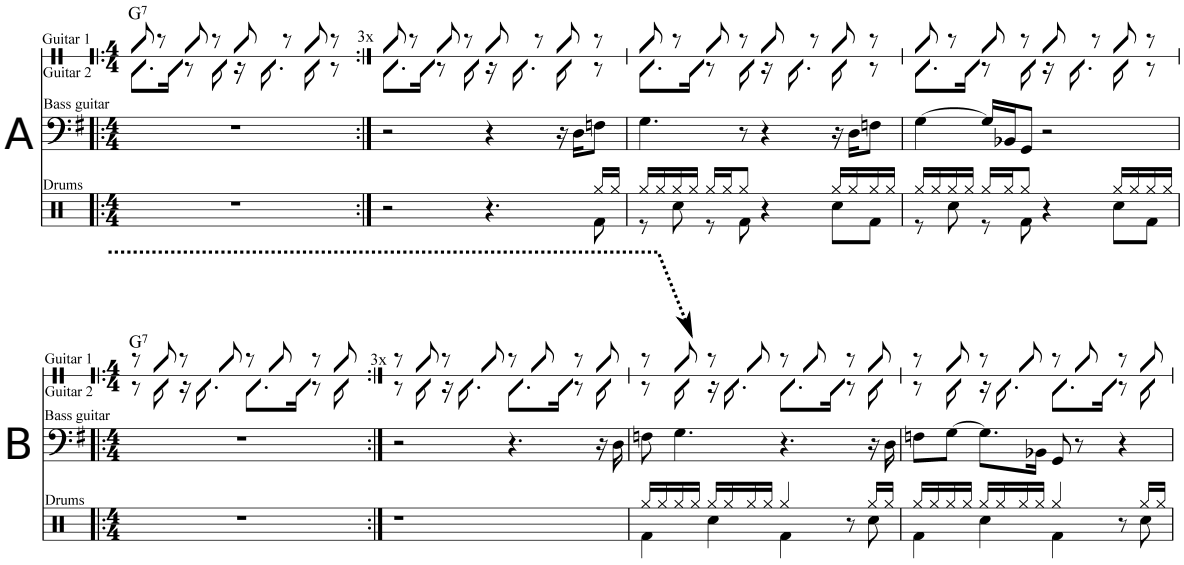
[5]Shaffer, Clarke, and Todd (1985); Longuet-Higgins and Lee (1984); (Drake et al., 2000, p. 3); (Sloboda, 1985, p. 276); Palmer (1989); (Drake et al., 2000, p. 3).

[6]Sloboda (1985) revisited and expanded on the same experimental design using artificially generated stimuli: Again, though some combinations of micro-timing, dynamics, and articulation resulted in better than chance performance, performance was generally not perfect (Sloboda, 1985, pp. 288–290).

[7]Of course, these were very unmusical rhythmic performances (repeating a single note on the piano), and Gabrielsson argued that the pianist was simply too 'subtle' with his performance. Still, these are *post hoc* explanations of the communicative failure; researcher and performer both *a priori* believed the metric interpretation would be evident from the performance.

[8]Parncutt randomized the starting event of each rhythm in his experiment specifically so as to avoid primacy effects; the resulting ambiguity of phase in his data may in part be a result of this. However, his report aggregates data across all start locations, so that this explanation cannot be confirmed (1994, pp. 415–419)

Figure 1. Illustration of a 'metric fake-out' in *Wake Up* by the band XTC. Figure 1A illustrates the metric interpretation of this passage which listeners tend to hear at first. Figure 1B illustrates the metric interpretation that most listeners switch to when the drums enter, as indicated by the dashed arrow.



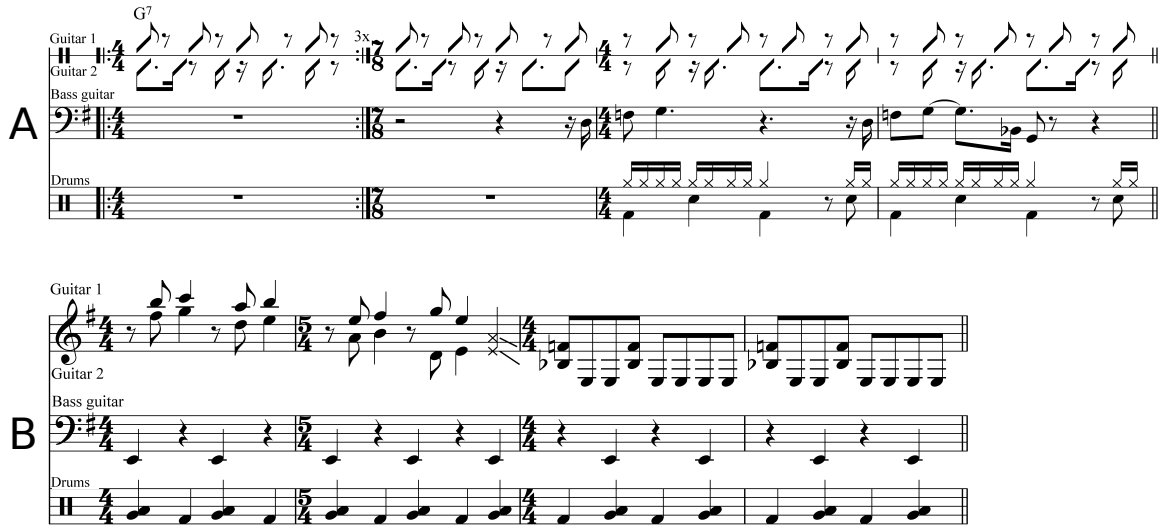
measures of this piece the guitar parts are typically perceived as shown in Figure 1A, with the rhythmic figure beginning on the downbeat. However, this metric interpretation of the guitars leads to an implausible interpretation of the drum and bass parts once they enter (later part of Figure 1A). Most listeners quickly switch to hearing the kick and snare drum attacks landing on the beats—a variation of 'the standard rock beat' (Biamonte, 2014, ¶ 6.1)—, displacing the guitar attacks onto offbeats as shown in Figure 1B. Thus, a dramatic contrast is made between two plausible metric interpretations of a single musical figure.

Biamonte classifies fake-outs as *initiating dissonances*, which serve to 'mark the beginning of a phrase or section' (2014, ¶ 7.2). Drawing on Krebs' theoretical model, she identifies fake-outs as examples of *indirect metric dissonance*, since the dissonance occurs 'successively between phrases or sections' (Krebs, 1999; Biamonte, 2014, ¶ 2.1,4.1–4.2). As a result, any rhythmic 'dissonance' is only perceived during, and/or retrospectively after, the change of interpretation.

Fake-outs are particularly common in popular music, often occuring as a result of what Spicer (2004) calls *accumulative form*, wherein instruments are gradually added to the arrangement. Butler (2006, pp. 124–130) describes fake-outs in Electronic Dance Music, referring to them as examples of 'ambiguity of beginning.'[9] However, scholars such as Karpinsky (2012) and Temperley (2001) have discussed similar examples in classical music.

[9]Even the early blues recording *Boogie Chillen* (1948) features similar metric ambiguity (Benadon & Gioia, 2009).

Figure 2. Illustration of two fake-outs interpreted as irregular measures. Figure 2A illustrates *Wake Up* interpreted with a single measure of $\frac{7}{8}$. Figure 2B illustrates *Ride the Lightning* (by Metallica) interpreted with a single measure of $\frac{5}{4}$.



Phenomenology

London's expression 'fake-out' is certainly an apt description of the subjective experience many of us have when hearing passages like the introduction to *Wake Up*. Realizing we have been fooled into hearing the metre incorrectly, we quickly (perhaps with a twinge of embarrassment) switch to the correct interpretation. However, this is not the only way to describe the experience of such passages. A less colorful description is simply a *reorientation* to a different metric interpretation (Fitch, 2013, p. 3; Fitch & Rosenfeld, 2007, p. 45). Alternately, listeners may interpret these passages as having a stutter or 'hiccup' which momentarily breaks the steady metre (Hesselink, 2014, p. 86), or interpret these passages as a single irregular-but-in-time measure: Figure 2A illustrates how *Wake Up* can be interpreted with an irregular measure.[10] As another example, Figure 2B illustrates an irregular interpretation of a malleable passage from the song *Ride the Lightning* (1984) by Metallica. Since Metallica frequently includes irregular measures in their music, an interpretation like the one shown in Figure 2B is entirely plausible.

Terminology

The term *fake-out* implies that the initial interpretation is *fake* (wrong), while the interpretation that eventually stabilizes is *real* (correct). Thus, a possible implication of the fake-out concept is that listeners should prefer the 'real' metric interpretation of a passage. If so, we would expect listeners to avoid being fooled twice. Vazan and Schober (2004) conducted an empirical study whose chief goal was to test just this conjecture. Vazan and Schober played the song *Murder by Numbers* (1983) by the Police—which features a particularly lengthy metric fake-out—to twenty participants.

[10] Biamonte (2014, ¶ 4.1) describes a similar metric interpretation of *Tell Me Something Good* (1974) by Rufus with Chaka Khan, with an $\frac{1}{8}$ added at the transition from verse to chorus, and an $\frac{1}{8}$ deleted at the transition from chorus back to verse.

They wondered if participants would favor the 'globally consistent' hearing on repeated listening, or if they would favor the 'locally generated' (fake-out) interpretation. Vazan and Schober found that the majority of listeners simply resolved the metric ambiguity by interpreting a change of metre midway through the piece, even after multiple hearings and even when instructed to find the globally consistent hearing.[11] Ultimately, the 'expectation that participants would progressively [move towards the correct hearing] did not materialize' (Vazan & Schober, 2004).

In general, making judgements about the right or wrong way to experience music is inappropriate. Rather than referring to a 'correct' interpretation, this paper will adapt Vazan and Schober's terminology and refer to the *consistent* interpretation. In the consistent interpretation a single consistent metre is heard throughout the passage without any need for a reorientation, stutter, or irregular measure. Figure 1B illustrates the consistent hearing of *Wake Up*. Conversely, fake-outs and reorientations can be regarded as *inconsistent* metric interpretations: the perception of the metre may itself be inconsistent, as in Figure 2, or the same musical part may be interpreted inconsistently, as when a listener switches between Figures 1A and 1B. In most cases there is only one plausible inconsistent interpretation of a given passage, which I will refer to as the passage's *alternate* interpretation.

Inconsistent metric interpretations can actually be very dependable. For instance, most listeners hear the inconsistent (fake-out) interpretation of *Wake Up* every time they hear the piece. Thus, Agawu's (1994, p. 86) assertion that 'on each occasion a listener will hear the passage in terms of a particular metrical organization' can hold true even when this perceived metrical organization includes an 'inconsistent' interpretation of the metre.

Performers' perspective

It is difficult to determine whether composers and performers purposefully create metric fake-outs, or whether they are aware of potential ambiguities. Most scholars seem to believe that fake-outs are intentionally created by composers/performers: Biamonte (2014, ¶ 7.2) describes fake-outs as formal 'attention-getting devices,' while Spicer (2004, p. 33) explicitly suggests that metric ambiguity in rock grooves constitutes a 'deliberate attempt to surprise the listener.' In the most extensive discussion of the subject, Hesselink (2014) characterizes two examples of metric ambiguity in popular music—from the Police's *Bring on the Night* (1979) and Radiohead's *Pyramid Song* (2001)—as conscious 'rhythmic play' on the part of the composers/performers, and supports this claim by analyzing interviews with band members. It is difficult to imagine classical composers creating interesting rhythmic ambiguity by accident.[12] However, the possibility of unintentional metric ambiguity should not be discounted. Performers and composers have biased perceptions of the music they create; they are intimately familiar with how a piece is 'supposed' to sound and, as a result, it is entirely possible for them to not anticipate an alternate hearing, even if it seems obvious to an independent listener. Furthermore, performers are typically counting and/or feeling the intended metre before and as they play, so they are rarely put in the position of inferring the metre from the music. Regarding popular music, both the Police and Radiohead represent extremes in terms of rhythmic sophistication—many fake-outs occur in straightforward rock. In regards to classical music, even Karpinsky (2012, ¶ 3.2–3.3)

[11] Whether these changes of metre were experienced as non-metric reorientations or smooth metric irregularities is not clear from Vazan and Schober's report.

[12] Brahms in particular is often noted for his sophisticated, no doubt intentional, metric play (Smith, 2006).

doesn't necessarily endorse the idea that composers are aware of what they're doing, contrasting 'the way Saint-Saëns intended' with his own experience, and stating that Beethoven had been 'thinking' of the consistent metric interpretation 'from the get-go.'

In most cases, conclusively determining the intent of composers/performers is impossible (Hesselink's (2014) example is a rarity). Generally, it seems safe to assume that the consistent interpretation is the metre felt by, and intended to be conveyed by, the performer(s). Direct evidence for this assumption is not easy to come by, but some indirect evidence can be found: Regarding the Metallica songs used in Study 2, the band's drummer counts off the consistent interpretation in live performances of all four songs. Since Metallica's music frequently contains mixed metre, it would not be implausible for them to begin the piece using an alternative interpretation and then include an irregular measure (as in Figure 2B); However, it seems Metallica prefers to perform the piece by counting the consistent interpretation of the metre.

Listeners' perspective

One of the most intriguing results of Vazan and Schober's (2004) study of *Murder by Numbers* was the great deal of variation they observed between listeners.[13] Since metre recognition is most likely learned (at least in part) it is not surprising that listeners might have small differences in their metric preferences; Given relatively ambiguous stimuli, these listeners might then have different metric experiences. As a concrete example, *shift syncopations*—wherein musical events normally associated with a strong beat are played slightly before the beat—are common in rock music but nearly unheard of in classical music (Temperley, 1999). Thus, a classical listener who never listens to rock music might be 'fooled' by shift syncopations, whereas an experienced rock listener would not. Cross-cultural differences in rhythmic perception have been identified (Iversen, Patel, & Ohgushi, 2008; Kalender, Trehub, & Schellenberg, 2012), but the possibility that small differences in experience between listeners within the same culture could result in different percepts has not been formally studied.

A final question to consider is the extent to which metric interpretation is voluntary: the role of 'the intentionality of hearing' (Guck, 2006, p. 194). In the visual realm, perception of the Necker Cube can be switched quite easily, while perception of the Spinning Dancer is difficult to control. Whether listeners generally have voluntary control over their metric perception when listening to real music has not been firmly established. According to London, 'Musically trained listeners can often self-consciously reconstrue a rhythmic surface' (London, 2004, p. 51). Iversen (2009) observed neurological evidence that participants could indeed impose alternate metric interpretations of a simple /1:2/ rhythmic pattern. In contrast, Karpinksy (2012, ¶ 3.6) observed that he is not always able to control his metric experience, even of highly familiar pieces. Indeed, while controlling the metric level of one's entrainment (i.e. 𝅗𝅥 or ♩ within $\frac{4}{4}$) has been shown to be relatively easy (Drake et al., 2000), even relatively simple reinterpretations of metric phase or cardinality have proven difficult to demonstrate in controlled experiments (Vazan & Schober, 2000). In Vazan and Schrober's study (2004), one group of participants was specifically instructed to search out the consistent metric interpretation of the song over the course of multiple listenings but, as mentioned before, participants' ability to find the consistent interpretation of *Murder by Numbers* was negligible.

[13]Butler (2006, pp. 125–126) also observes that different listeners sometimes experience different metric interpretations.

Current Studies

Metric fake-outs are tangible instances of multi-stable perception in music. From theoretical, compositional, and performance perspectives these passages are fascinating musical events. Fake-outs attest to the richness of musical experience—how composers can play with their audiences, and the role audiences play in their own subjective experience of music (Guck, 2006). From a cognitive perspective, metric ambiguity provides a useful avenue for studying the perception of metre in general. If metre is experienced inconsistently, either between or within listeners, it raises many interesting questions concerning the cognition of rhythm and the shared experience of music.

To date, most discussion of fake-outs, and metric ambiguity in general, has been theoretical, driven by the intuitive observations of theorists and musicians. The prominent exception (Vazan & Schober, 2004) used only a single song as stimuli—a song by a particularly sophisticated artist (the Police), which may represent an outlier in the body of music as a whole. This paper seeks to more thoroughly ground the discussion in a mixture of qualitative and quantitative empirical evidence. Empirical data was gathered in three studies: 1) a limited exploratory study of metric ambiguity in several large samples of popular music; 2) an exploratory study of the perception of twenty-four metrically-malleable musical passages; and 3) a controlled experiment concerning the role of the *Strong Beat Early* rule (Lerdahl & Jackendoff, 1983, p. 76) in metric induction.

Typology

London (2006) identifies eight fake-out types, but his categories are imperfect and (as he admits) include some redundancy.[14] In fact, I propose that London's typology can be effectively abstracted to two basic dimensions: 1) 'fake' metric *period* (grouping dissonance) and 2) 'fake' metric *phase* (displacement dissonance). Regarding periodic fake-outs, it is important to further distinguish between fake periods at the beat level (i.e. a ♩ tactus mistaken for ♩.) or measure level (i.e. a $\frac{3}{4}$ measure mistaken for $\frac{4}{4}$). Few other periodic confusions are likely, since any power of two relationship is unlikely to be heard as a fake-out: confusing ♩ → 𝅗𝅥 or $\frac{2}{4} \rightarrow \frac{4}{4}$ isn't really perceived as a much of a 'mistake' in most cases.[15] Periodic fake-outs at levels below the tactus—for instance, confusing $\frac{12}{8}$ (♩. = 90bpm) and $\frac{4}{4}$ (♩ = 90bpm)—are hard to achieve since music frequently mixes triple and duple subdivisions anyway. Periodic fake-outs at the hypermetric level are also difficult to achieve.[16] Table 1 shows how my fake-out dimensions relate to London's (2006) four principle fake-out categories.

Of the two basic fake-out dimensions, displacement fake-outs seem to be more prevalent: Displacement 'errors' are evident in the experiments of Gabrielsson (1973), Sloboda (1983), Vos et al. (1981), Parncutt (1994), and Drake et al. (2000), discussed above. In fact, Drake et al. observed participants tapping to the incorrect phase of metre in about 7% of their otherwise successful trials, while in some cases non-musicians

[14]London (2006) also includes 'metric vagueness' as a fake-out type. However, I prefer to consider fake-outs as the contrast between two clear, *stable* interpretations; Vague metre is an interesting musical effect in its own right, but not a fake-out.

[15]There are some exceptions: for instance, Joni Mitchell's *Help Me* (1974) begins with a guitar strumming pattern which suggests a fast tactus, but which is instantly thwarted when the ensemble enters, strongly projecting a beat at half the speed.

[16]One could argue that the expectation of duple at hyper-metric levels is so strong that any violation of duple-hyper metric period is *always* heard as a fake-out.

London's term	Fake tactus period	Fake higher period	Displacement (fake phase)
Garden Pathing 1	☐	☐	☑
Garden Pathing 2	☑	☐	☐ or ☑
Garden Pathing 3	☐	☑	☐ or ☑
GP4 (or Non-isochronous)	☑	☑	☐ or ☑

Table 1. Relationship between London's fake-out classifications and my fake-out dimensions.

tapped the wrong phase as much as half the time (2000, pp. 15–16).[17] Unlike periodic fake-outs, the magnitude of metric displacement is highly varied, and has a major impact on the music's feel. In general, displacements at a given metric level alter the relative metric status of all higher metric levels, but not lower levels (Drake et al., 2000, pp. 14–15; Biamonte, 2014, ¶ 1.3). For instance, a ♩ displacement will alter the relationship between attacks at the 𝅗𝅥 and 𝅝 metric levels, but will not change the relationship between sub-tactus beats (♪ or 𝅘𝅥𝅯). Throughout this article, the consistent interpretation is encoded as /0/, with displacements coded relative to this baseline using musical duration symbols to indicate magnitude, and the symbols /+/ and /-/ to indicate direction. The /+/ symbol indicates that the interpretation is displaced earlier than the consistent interpretation, while the /-/ symbol indicates it is shifted later. *Wake Up* features a displacement of the metre one ♪ late (-♪), while *Ride the Lightning* is displaced one ♩ early (+♩).

The typological discussion so far has only considered the metric structure of fake-outs, but there are several other factors which are important to consider. One such factor is the length of the fake-out: how long the alternate metric interpretation is maintained before the consistent interpretation becomes apparent. Listeners begin forming an impression of the beat very rapidly—musicians are typically able to tap along with the beat after hearing four to six beats (Snyder & Krumhansl, 2001, p. 466).[18] The length of time required to form an impression of the metric hierarchy is not as well known, though anecdotal experience suggests that some passages may evoke a clear metre almost instantly, while others require considerably more time. Thus, it is possible to experience extremely short fake-outs. As example, in the Police's *Spirits in the Material World* (1981) the very first chord played by the keyboard, after the opening drum fill, sounds to me like a downbeat, but the drum part forces me to switch to the consistent interpretation almost immediately.

A final typological distinction to be made regarding fake-outs is whether the same musical figure is actually reinterpreted. In *Wake Up* the two-guitar rhythmic pattern repeats exactly throughout the passage—only one's interpretation of it changes. In contrast, in *Ride the Lightning* the fake-out occurs when the guitar parts switch to playing a completely unrelated riff—each guitar riff/melody is heard in only one interpretation, so there is no direct contrast of metric interpretation. It is in these cases that a metric interpretation that includes a extra or missing beat is most plausible.[19]

[17] It is always possible that participants' tapping does not reflect their underlying sense of the metre, a point which should be kept in mind when considering experiments involving tapping data, including my experiment reported below.

[18] Eight or more beats may be required for music featuring expressive rubato (Drake et al., 2000, p. 10).

[19] In the case of *Ride the Lightning*, the drum part does remain static through the change of interpretation, offering the only clue that the single measure of $\frac{5}{4}$ (Figure 2B) is not the consistent interpretation.

Study 1: Fake-out Prevalence

Precisely how common metric fake-outs are is difficult to determine. A systematic search for fake-outs in the body of popular music as a whole is impossible; Even if discussion is restricted to studio-recorded, commercially released, Anglophone popular music—as this paper does—the repertoire/population is still enormous and ill-defined. What's more, identifying fake-outs requires musically literate human listeners and, due to interpersonal variation in metric perception, any one listener can only identify fake-outs they themselves experience. Thus, to statistically estimate how often fake-outs occur when people listen to music would require both a representative random sample of songs and a representative random sample of listeners. Achieving both of these goals is far beyond the scope of the current project. Instead, limited preliminary attempts at each sampling goal in isolation are presented: In this section, I will consider large pseudo-random samples of popular songs as experienced by one listener (myself). In subsequent sections, I will draw upon the data from multiple musicians listening to a relatively small, non-random sample of songs.

To get a rough estimate of the prevalence of fake-out passages in popular music, I personally listened to the introductory sections of two large samples of songs. The procedure was to listen to the beginning of each track until a consistent metric interpretation became evident (ignoring any rubato material), noting my own natural metric interpretation of the music as it unfolded.[20] I was open to any type of metric ambiguity, but was particularly focused on fake-outs created by displacement dissonances. For each song which elicited a fake-out, I noted whether the fake-out was persistent (whether I experienced it when listening to the track multiple times), how long it lasted before I switched to hearing the consistent interpretation, and the direction and magnitude of the displacement.

The first sample in the survey was Rolling Stone's '500 Greatest Songs of All Time' (2004), which is by no means a random sample, but rather a critically assembled list of exceptional songs. The second sample is the McGill Billboard Corpus (Burgoyne, 2011), a sample of 739 unique records which appeared on the Billboard Hot 100 chart between 1958–1991. The Billboard sample is a stratified random sample of the Hot 100; however, Billboard is not itself a representative sample of popular music, but a representation of the most popular songs released as singles. Both samples are heavily biased towards music released before 2000, and especially before 1991. The two samples also intersect, with 42 songs shared between them. Both samples contain many songs familiar to myself, though the majority of songs (especially in the Billboard sample) were unfamiliar. For familiar songs, the metric experience I document represents the result of repeated listenings to the piece, in some cases over many years. In these cases only significant metric ambiguity which persists over many listenings is likely to be recorded. In contrast, unfamiliar songs in the sample represent fresh, first-time metric interpretations, and I was careful to note any ambiguous experiences I had, even if they did not persist on repeated listenings.

In the course of the survey I had a variety of metrically ambiguous experiences. However, most of these experiences did not resolve into clear, persistent fake-outs in the vein of *Wake Up* or *Ride the Lightning*, but were instead subtle and/or fleeting. For the purpose of this study I define a 'true fake-out' as an experience wherein I consistently form a strong impression of the metric hierarchy which is subsequently displaced. The Fake-Out column of Table 2 tallies fake-outs which meet these criteria. The Ambiguity column adds to this tally passages that evoked any metric ambiguity, no matter how

[20] Passages which feature truly irregular or mixed metre were not counted.

Table 2. Number of songs evoke Fake-outs in myself, in four different samples.

Sample	Decade	Total	Fake-Out	Ambiguity
Rolling Stone	All	500	8 ($\approx$ 1 in 63)	25 ($\approx$ 1 in 20)
McGill Billboard	All	740	13 ($\approx$ 1 in 57)	59 ($\approx$ 1 in 13)
	1958–1969	236	3 ($\approx$ 1 in 79)	21 ($\approx$ 1 in 11)
	1970–1979	262	5 ($\approx$ 1 in 52)	18 ($\approx$ 1 in 15)
	1980–1991	242	5 ($\approx$ 1 in 48)	20 ($\approx$ 1 in 12)

short, even if only experienced once. Across the two samples, I experienced metric ambiguity of some sort in approximately one out of every thirteen to twenty songs, and more distinct displacement fake-outs in approximately one in every sixty songs (about 1.7%). However, even some of the fake-outs I include in the tally are extremely short, lasting a measure of less. For instance, three of the sampled fake-outs I experience—in Led Zeppelin's *D'yer Mak'er* (1973), Bonnie Pointer's *Heaven Must Have Sent You* (1978), and B.B. King's *the Thrill is Gone* (1969)—consist only of an ambiguous drum fill, approximately one measure in length. In each sample, only six (Rolling Stone) and seven (Billboard) tracks respectively evoke persistent displaced interpretations that (as in *Wake Up*) persist through more than one measure of music.

These two samples give us a rough impression of the prevalence of metric ambiguity in a variety of commercially successful popular songs. Metric ambiguity is, of course, certainly more prevalent in some sub-sets of popular music: drawing upon my own personal music library, I experience clear metric fake-outs in six out of eighty-six tracks by Led Zeppelin and eight out of ninety-four tracks by Metallica—respectively four and five times the fake-out rate in the more broad samples. However, as can be seen in the by-decade subsets of the Billboard data, no change over time seems evident. As a reminder, this is data only reflects my personal experience. In fact, I know for certain that several songs which appear in the samples which I never experience as ambiguous do sometimes fake other people out, including Hendrix's rendition of *All Along the Watchtower* (which is discussed more below), Led Zeppelin's *Black Dog*, and the Beatles' *I Want to Hold Your Hand*. If this experiment could be reproduced with a larger variety of listeners, the number of songs which evoke fake-outs in at least some listeners might prove to be much greater.

London (2006) has already initiated a project to document fake-outs in popular music, identifying thirty-six fake-out passages in popular songs, which he shares in spreadsheet on his personal web page. Based on the listening described here, I've identified fifty additional musical passages which evoke fake-outs (for me). London's list, though a smaller sample of songs, has a much larger group of contributors (sixteen named contributors). A complete list, amalgamating London's existing list with my own, is hosted in a spreadsheet at fathermckenzie.com/musicTheory/metre/metricambiguity.

Study 2: Exploratory case studies

The remainder of the paper will focus on the study of the twenty-four pieces listed in Table 3. These fake-outs were drawn from my own experience, the existing literature, and from suggestions made by colleagues.[21] In addition to these twenty-four passages, eleven control passages were selected (Table 4). The controls were similar pieces that I do not perceive as ambiguous in any way. Interestingly, one passage, the Beethoven *Sonata 19* first movement, was originally selected as a control stimuli, but was found

[21] Thanks to Claire Arthur, and Jeremy Cross.

Table 3. Stimuli used in Study 2. The displacement column indicates how the most common alternative metric interpretation of the passage is displaced relative to the consistent metric interpretation. /+/ indicates a displacement earlier than the consistent interpretation while /-/ indicates displacements later than the consistent interpretation. For instance, /+♪ means that all the beats in the alternate interpretation are heard one ♪ earlier than the corresponding beats in the consistent interpretation. Each alternate interpretation is illustrated in Figure 3. All passages are in $\frac{4}{4}$ time unless otherwise indicated.

Song	Artist	Displacement	Contributor
Heresy (1994)	Nine Inch Nails	−𝅘𝅥𝅯	Author
Sonata No. 10, 1st Movement (1799)	Ludwig van Beethoven	−♪ $\frac{2}{4}$	Author
Wake Up (1984)	XTC	−♪	London
See You (1982)	Depeche Mode	−♪	London
I Wish I Had an Evil Twin (2004)	The Magnetic Fields	−♪	London
Janie's Got A Gun (1989)	Aerosmith	−♩	London
She's A Woman (1964)	The Beatles	−♩	Author
I Robot (1977)	The Alan Parsons Project	+𝅘𝅥𝅯	Spicer
Pigs (Three Different Ones) (1977)	Pink Floyd	+𝅘𝅥𝅯	Author
Sonata No. 19, 2nd Movement (1805)	Ludwig van Beethoven	+♪ $\frac{2}{4}$	Controls
Concerto No. 1, 3rd Movement (1798)	Ludwig van Beethoven	+♪ $\frac{2}{4}$	Karpinksy
Kate (1997)	Ben Folds Five	+♪	Colleague
I'm Free (1969)	The Who	+♪	London
All My Life (2002)	The Foo Fighters	+♪	Colleague
Good Times Roll (1978)	The Cars	+♪	London
Holier Than Thou (1991)	Metallica	+♪	Author
All Along the Watchtower (1968)	Jimi Hendrix	+♪	London
Caroline No (1966)	The Beach Boys	+♪	London
Intermezzo in A, Opus 76 No. 6 (1871)	Johannes Brahms	+♪ $\frac{2}{4}$	Author
Intermezzo in Eb, Opus 117 No. 1 (1892)	Johannes Brahms	+♪ $\frac{6}{8}$	Colleague
Third Symphony, 2nd Movement (1886)	Camille Saint-SaëNS	+♩ $\frac{6}{8}$	Karpinsky
Ain't My Bitch (1996)	Metallica	+♩	Author
Ride the Lightning (1984)	Metallica	+♩	Author
Amazing Journey (1969)	The Who	+♩.	Author

to evoke fake-outs in more than half of participants, and is thus considered among the fake-out passages.

The twenty-four passages considered here all feature displacement (phase) fake-outs. This focus limits the metric preference rules that can be directly studied.[22] I also focus on fake-outs which establish a clear metre beat for at least one complete measure—shorter fake-outs are too fleeting to be easily measurable.[23]

The consistent metric interpretation of each excerpt, as well as the most common alternate interpretation, is transcribed in Figure 3. Nineteen of the twenty-four excerpts feature sub-tactus displacements (smaller than the tactus beat), and four excerpts feature tactus-level displacements. Finally, *Amazing Journey* features a displacement of -♩., affecting both sub-tactus and tactus metric levels. All the pieces studied here are in duple metre, though two are examples of compound duple ($\frac{6}{8}$). No supra-tactus (𝅗𝅥 or 𝅝) displacements are included in this study.[24] The only excerpts that show truly indirect

[22]For instance, by ignoring grouping dissonance, we unambiguously evoke GTTM's parallel rule (Lerdahl & Jackendoff, 1983, p. 75), placing this rule outside the bounds of the current study.

[23]In fact, several of the fake-outs passages used here had to be edited to make the metrically malleable passages longer; for instance, participants listened to a version of *I'm Free* in which the first measure of music repeats twice before moving on to the second measure.

[24]Such fake-outs have been observed (London, 2006), including one example in the Rolling Stone sample: the opening of the Verve's *Bitter Sweet Symphony* (1997), which I tend to hear with a hypermetric displacement

Table 4. Sources of control stimuli used in Study 1.

Song	Artist
Pet Sounds (1966)	the Beach Boys
Day Tripper (1965)	the Beatles
Capriccio in B minor, Op.76 (1871)	Johannes Brahms
Purple Haze (1970)	Jimi Hendrix
Sweet Home Alabama (1974)	Lynyrd Skynyrd
the Great Gig in the Sky (1973)	Pink Floyd
Roxanne (1978)	the Police
Crazy Little Thing Called Love (1980)	Queen
Karma Police (1997)	Radiohead
Through the Never (1991)	Metallica
the Seeker (1979)	the Who

metric contrasts are *All Along the Watchtower* and *Holier Than Thou*—meaning that no particular rhythmic figure is interpreted in multiple ways. *I'm Free* is an interesting case because the metrically malleable riff is interpreted in multiple ways, but only after an intervening section (the chorus) first triggers the reorientation.

I observed the metric induction behaviour of seventeen participants, recruited from a convenience sample of undergraduate music students.[25] It was stressed to the participants that their abilities were not being tested, and that finding the 'correct' metric interpretation was not their task. Rather, their task was to honestly report their experience of the music. I sat behind each participant during listening and observed which metric interpretation each participant counted in each measure of each excerpt. Each excerpt was played twice for each participant. To focus participants' attention on the relevant beat level[26], and to prepare them for each piece's tempo and metric period, a drum track at the appropriate tempo was played for the participant before each piece.

In a second task, intended to test participants' voluntary control of their metric perception, special versions of nine of the excerpts[27] were edited so as to loop the multi-stable portion of the excerpt. Two possible interpretations of each excerpt were explicitly explained (using notated examples) to each participant. Each participant was asked to count along to the music for several measures in one interpretation, then to stop and begin counting along in the other interpretation. If the participant proved unable to switch their metric experience, I would demonstrate the alternate interpretation myself to see if this helped them reorient.

Summary of Results

Figures 4 and 5 convey the results of all observations of each excerpt condensed onto a single timeline, representing which interpretations were tapped by participants at any given point. Two pieces, *Kate* and *All My Life*, were always interpreted the same way by all participants. *All Along the Watchtower* was interpreted a variety of ways but no participants switched interpretation mid excerpt. Most of the remaining excerpts did evoke fake-outs for at least some participants, with *Wake Up*, *Holier Than Thou*, *I'm Free*, and *Good Times Roll* being the cleanest examples. Except for *Sonata 19*, all the control excerpts were immediately heard in their consistent interpretation.

As can be seen in Figure 4 and 5, a variety of interpretations were observed that are neither consistent nor fake-outs, including many instances of participants continuing

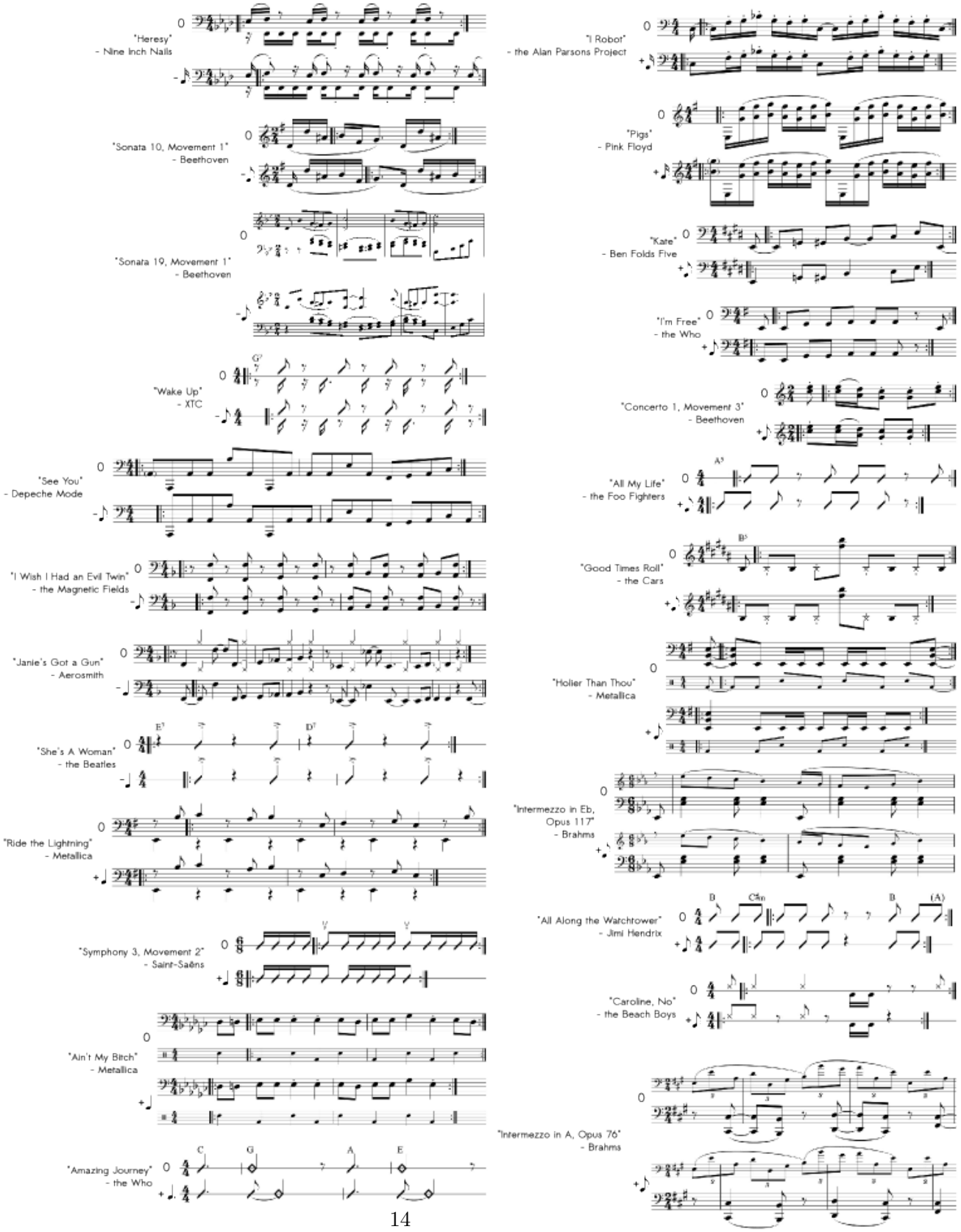
of one measure.

[25] Feel free to contact the author for complete methodological details.

[26] Perceiving tactus is known to be somewhat subjective (Martens, 2011).

[27] *All My Life*, *Sonata 10*, *Caroline No*, *Concerto 1*, *I'm Free*, *Kate*, *Pigs*, She's a Woman, and *Wake Up*

Figure 3. Reduced transcriptions of multi-stable passages from each excerpt. The upper staff in each stave, illustrates the consistent metric interpretation of the passage while the lower staff illustrates an alternate metric interpretation of the same passage, coded in terms of its displacement earlier (/+/) or later (/-/) than the consistent interpretation.



to tap the alternate interpretation after the expected point of reorientation.[28] Some of this variability may be noise due to the unnaturalness of the experimental task; for instance, participants may have been feeling the consistent interpretation while counting an alternate interpretation. There is also the possibility that participants might have felt pressure to 'stick to their guns' and continue tapping their original interpretation no matter what; such a conservative hearing strategy (Lerdahl & Jackendoff, 1983, pp. 22-25), which precludes fake-out experiences, might be the norm for many listeners. Notice in general that the excerpts drawn from the classical repertoire also feature ample variation in metric interpretation despite the great degree of dynamic and timing performance freedom in this genre. In the case of the excerpt from Beethoven's *Concerto 1*, although the performer in the recording clearly accents the downbeat of the consistent interpretation, seven out of eleven participants—like Karpinsky (2012)—heard the alternate interpretation at least once.

Recall that participants heard each excerpt twice. Participants counted each hearing with essentially identical metric interpretations in 74% of observations, while either starting or ending the same in 82% and 84% respectively. Thus, there is some modest within-person variability evident in the data. However, consistent with Vazan and Schober's (2004) results, there is little evidence of participants preferring, or honing in on, the consistent interpretation. Participants tapped stably on alternate interpretations nearly as often as they tapped stably on the consistent interpretation, and stable interpretations on /0/ were no more common on second hearings than on first hearings. Only in 8 out of 222 observations did participants completely 'correct' their interpretation, making a 'mistake' on the first hearing while tapping only the consistent hearing on the second hearing. Thus, even when participants transitioned to the consistent interpretation of a piece on their first hearing, this did not generally allow them to immediately hear the consistent interpretation on their second hearing. Participants were, more often than not, fooled twice.

Each participant filled out a questionnaire related to their musical experience and preferences, but there was no evident relationship between participants' metric interpretations and their musical experience. Evidently, although listeners' experience of metrically ambiguous passages do vary greatly, this variation is not easily predictable from musical experience. A much larger sample of listeners will be required to identify consistent relationships between metric interpretation and musical experience, if any exist.

The later half of each session tested participants' ability to control their metric experience. For certain songs (particularly *All My Life*) participants were relatively successful at voluntarily switching their interpretations, whereas other songs were extremely difficult. Participants varied greatly in their ability to perform this task, but again there was no relationship between their performance and any of the questionnaire items.

Observations

These empirical observations (Figures 4 and 5) are most informative when considered in relation to the unique musical attributes of each excerpt. Combined with musical analyses, the data provides a basis for exploring the metric preference rules at play in the participants' experiences of these passages. Unfortunately, detailed analysis of all twenty-four examples is not possible here. Rather I will briefly discuss five broad topics which the data help illuminate.

[28] Vazan & Schober (2004) observed similar metric experiences.

Figure 4. The actual interpretations tapped by each participant at each measure of each excerpt on their first hearing. The horizontal axis represents time in musical measures. The vertical axis represents different metric interpretations of the music, in terms of their displacement relative to the consistent ('correct') interpretation in ♪ units. The thickness of lines indicates the number of participants who tapped each interpretation at any given point in the piece—the key at the top of the plot indicates how thickness relates to number of participants. Diagonal lines between interpretations represent places where participants switch from one interpretation to another. Annotations above the horizontal axis indicate various changes in the music at those points: /+/ indicates the entrance of an instrument while /∼/ indicates a change in the part for a given instrument. Instrument codes are /v/ (voice or violin), /b/ (bass guitar, or left-hand of piano), /g/ (guitar, /k/ (keyboards), /m/ (complete ensemble). /</ and />/ indicate the departure and return of the ambiguous musical figure.

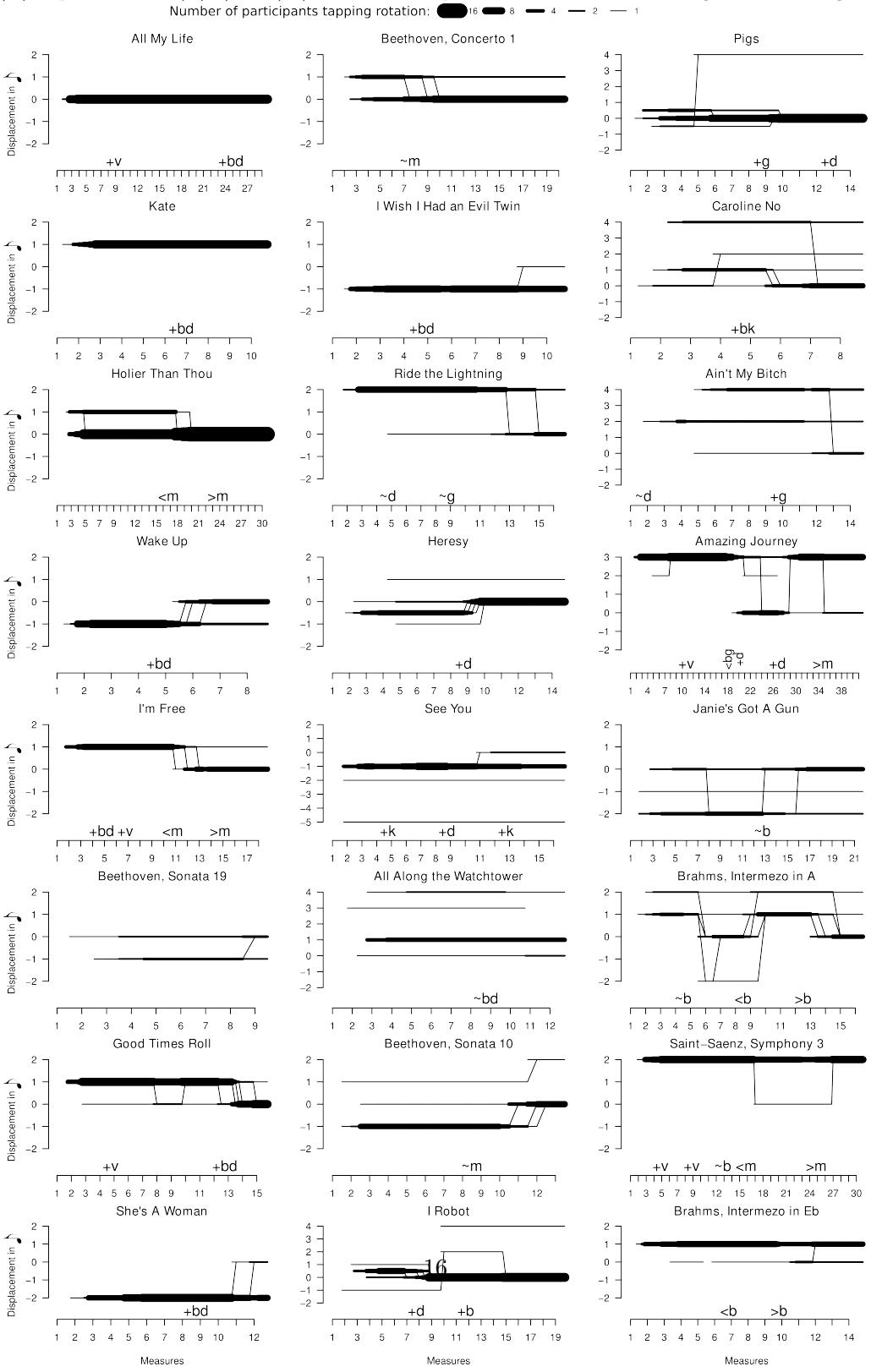
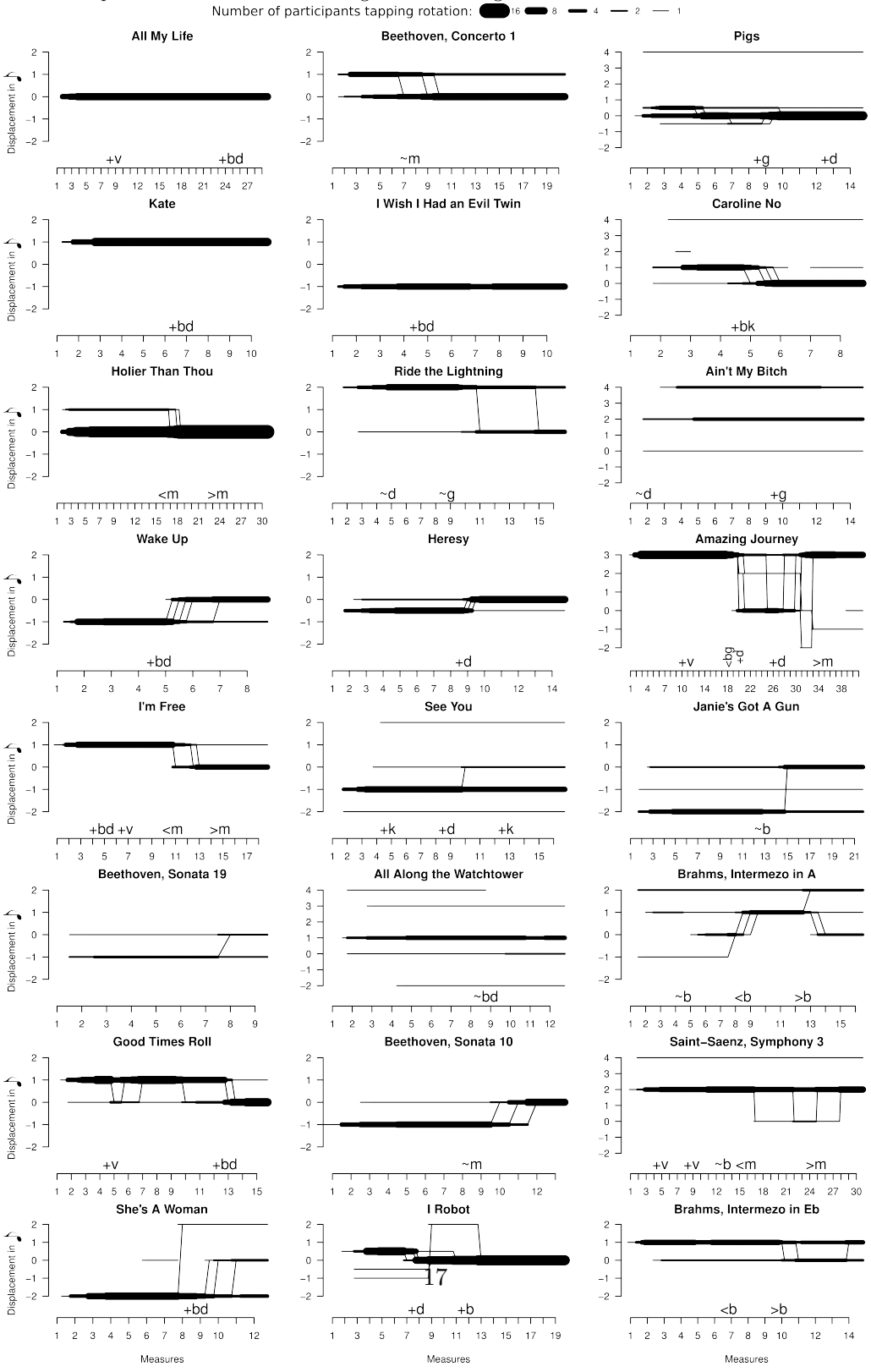


Figure 5. The actual interpretations tapped by each participant at each measure of each excerpt on their second hearing. The horizontal axis represents time in musical measures. The vertical axis represents different metric interpretations of the music, in terms of their displacement relative to the consistent ('correct') interpretation. The thickness of lines indicates the number of participants who tapped each interpretation at any given point in the piece—the key at the top of the plot indicates how thickness relates to number of participants. Diagonal lines between interpretations represent places where participants switch from one interpretation to another. Annotations above the horizontal axis indicate various changes in the music at those points: /+/ indicates the entrance of an instrument while /∼/ indicates a change in the part for a given instrument. Instrument codes are /v/ (voice), /b/ (bass guitar), /g/ (guitar, /k/ (keyboards), /m/ (complete ensemble). /</ and />/ indicate the departure and return of the ambiguous musical figure.



Back beats and offbeats

Several of the excerpts feature strong attacks at isochronous intervals. The simplest examples are *She's a Woman*, *I Wish I Had an Evil Twin* and *Good Times Roll*, but *Ride the Lightning* and *Wake Up* also feature prominent regular attacks. In each case, these regular strikes land on backbeats or offbeats in the consistent interpretation, yet are overwhelmingly heard as being on beat. Of course, interpreting regular pulses as beats, not syncopations, is perhaps the most basic metric induction rule (Lerdahl & Jackendoff, 1983, pp. 78–78). However, backbeats and offbeats are extraordinarily important in popular music: jazz musicians count in by snapping their fingers on backbeats and reggae often contains more attacks off the beat than on. Given this prevalence, we might expect enculturated listeners to hear isochronous attacks as back/offbeats. In fact, three participants did hear the consistent interpretations of these pieces on their first hearing (two on *Good Times Roll*, and one on *Ride the Lightning*). However, all three were slow to begin counting, taking two to four measures before they began, indicating that it required some thought to identify the consistent interpretation. What's more, the participant who counted the consistent interpretation of *Ride the Lightning* throughout indicated that they were very familiar with that song before listening, so their data point should be considered with a grain of salt.

Approximately one third of the participants were able to voluntarily control their experience of *She's a Woman* without help, while about half could do it with some guidance. Thus, it appears that many musicians are *able* to hear isochronous attacks as syncopations if prompted to do so. Only one participant reporting the ability to consciously control their interpretation of *Wake Up*. Evidently the $/3+3+3+3+4/$ pattern in the second guitar make this passage more difficult to interpret in any but the least syncopated interpretation (-♪).

Syncopation

Finding the least syncopated metric interpretation is clearly a fundamental metric preference (Lerdahl & Jackendoff, 1983, pp. 76–78; Longuet-Higgins & Lee, 1984): In a simple tapping experiment, Fitch and Rosenberg (2007) found that participants were likely to reorient their metric interpretations when presented with moderately or highly syncopated rhythms (Fitch & Rosenfeld, 2007, p. 50).[29] The current dataset also attests to the importance of syncopation; as with the backbeat passages, the least syncopated interpretation was generally preferred in most cases. However, important exceptions are evident: The consistent interpretation of *All Along the Watchtower* is slightly less syncopated than the alternative which the majority of participants experienced. Similarly, the highly syncopated alternative hearing of *Caroline No* was maintained by about half the participants, even on their second hearing.

Clear, idiomatic shift syncopations occur in five excerpts: *Amazing Journey*, *I Robot*, *Kate*, *Holier Than Thou*, and *Janie's Got A Gun*. In both *I Robot* and *Kate* shift syncopations 'tricked' all participants, except one who experienced the consistent interpretation of *I Robot* on his second hearing. In contrast, the shift syncopation in the consistent interpretation of *Holier Than Thou* was heard as such by over half of participants, even on their first hearing.[30] Nothing in the syntactic rhythmic dimension

[29] They also found that syncopated stimuli resulted in more variability in tapping, consistent with other work by Patel, Iversen, and andBruno H. Repp (2005). Whereas Patel et al. forced participants to hear a particular interpretation, in conditions where a listener could choose between more or less syncopated interpretations of the same stimuli, the less syncopated interpretation would be easier and more accurately entrained to.

[30] Some participants reported being mildly familiar with the piece (thought they had probably heard it before), but there seemed to be no connection between their familiarity and their interpretation.

of *Holier Than Thou* seems to suggest how so many listeners are able to identify this syncopation. *All Along the Watchtower* is interesting for including a harmonic shift syncopation, with harmonic changes occurring on weak beats. Changes of harmony are often important cues of metric position, and it may be this harmonic syncopation which drives listeners to the alternate interpretation, wherein harmonic changes occur on beats.

Finally, *Janie's Got a Gun* is an interesting case where the two most common interpretations are both highly syncopated. The alternate interpretation notated in Figure 3 (−♩) was heard by a plurality of listeners. It may be that the shift-syncopation of the first bass note of each two-measure phrase ahead of the downbeat is much more idiomatic than having the first bass-note come after the downbeat, as in the consistent interpretation. Still, three out of nine listeners heard the consistent interpretation without issue. In addition, two participants experienced an ♪-displaced interpretation which places the first bass attacks on strong beats, but which syncopates the ride cymbal attack and the later notes in the bass line.

2+1+1

Two excerpts, *All My Life* and *Kate*, feature different rotations of a /2+1+1/ pattern, and were the most consistently experienced among the participants: *All My Life* was heard in the consistent interpretation by all participants while *Kate* was heard in the alternate interpretation by all participants, even after the drums entered.[31] Thus, though the /2+1+1/ rhythm is theoretically highly metrically malleable, in two examples of real music listeners always heard one interpretation or the other, but not the same one. The interpretation of Kate is well explained by theoretical models, as it avoids syncopation and places the longest duration in the strongest metric position[32]—the association of longer events with stronger metric positions being another well-known preference (Longuet-Higgins & Lee, 1982; Lerdahl & Jackendoff, 1983, pp. 82–86). The consistent interpretation places all melodic emphasis on a syncopated position, so it is unsurprising that no participants experienced the piece this way.

With no changes of pitch, the excerpt from *All My Life* is the plainest rendition of /2+1+1/ possible. Still, *All My Life* showed no sign of metric ambiguity, with all participants parsing the pattern as /1+2+1/, placing the longest duration in the weakest metric position. The simplest cue that explains the lack of ambiguity evident in observations of *All My Life* is simply that the pattern starts on the downbeat of the consistent interpretation. However, *All My Life* did prove to be metrically malleable, as it was the easiest excerpt for participants to control their perception of: seven out of ten participants were successful without assistance, and only one was unable to change their interpretation at all.[33]

Multiple reorientation

Six of the excerpts used in this study include a return to the initially ambiguous material after the initial fake-out. In Figures 4 and 5 these excerpts have /</ and />/ symbols marking the diversion from, and return to, the ambiguous material. In the cases of *I'm Free* and *Holier Than Thou*, participants never switched back to the alternate interpretation after leaving it for the consistent interpretation. In contrast,

[31]The slightly unusually drum beat in the excerpt (a variation of the standard rock beat) likely contributed to this failure to find the consistent interpretation. Unfortunately, I cut off the playback just as the vocalist enters, and I suspect that given more time most listeners would have switched to the consistent interpretation.
[32]The riff in *Kate* further emphasizes the long durations by making them the first onset, the lowest and most tonally stable pitches ($\hat{1}$ and $\hat{5}$), as well as the arrival point of the only large melodic leap (an octave).
[33]Kate was also reasonably successful, with five out of nine successful attempts.

when listening to the Saint-Saëns Symphony excerpt, two participants reoriented to the consistent interpretation at measure seventeen and then switched back to the /+♩/ interpretation as soon as the ambiguous motive returned.[34] Finally, in *Amazing Journey* most participants switched back to the alternate hearing at the return of the ambiguous opening rhythmic figure.

Idiomatic patterns

The importance of the rock drum beat in establishing metre has been noted several times (London, 2012, pp. 19,67–68). This suggests that abstract timing rules are not enough to govern metric interpretation, but that specific timbres and idiomatic gestures are important as well. However, in both *I'm Free* (current study) and *Tell Me Something Good* (Biamonte, 2014) listeners frequently hear the normative rock beat displaced by an ♪. Similarly, the excerpt from *Ain't My Bitch* features a clear standard rock drum beat throughout, yet the most common interpretation of this passage is displaced by +♩—'flipping' the pattern such that the snare drum attacks on beats 1 and 3. This flipped drum beat pattern is not extremely uncommon (it occurs in Metallica's music fairly regularly), but it is certainly less normative than the standard beat. Nothing in the guitar riff of *Ain't My Bitch* seems to strongly favor either interpretation.[35] Rather, the only thing that favors the alternate interpretation strongly is simply that the riff begins with the downbeat of this interpretation—the consistent interpretation requires hearing a ♩ pickup.

The consistent interpretation of *Amazing Journey* places the longest duration on a stronger beat, and thus is theoretically preferable (Lerdahl & Jackendoff, 1983, pp. 82–86). However, all participants heard the /+♩./ interpretation of this passage.[36] A possible explanation is that the /3+5/ rhythm articulated in this interpretation (rather than /5+3/) is a very idiomatic rhythm in rock, once again highlighting the role of idiomatic gestures in metric perception.

Study 3: Strong Beat Early experiment

In studies 1 and 2, we observe a tendency to interpret pick-ups and shift syncopations as downbeats, but not the other way around: Of the thirty-five fake-out-evoking passages identified in Study 1, all begin with a rhythmic onset off the downbeat. Of the twenty-four excerpts from Study 2, thirteen of the alternate hearings involve a mishearing of a pick-up or anticipatory shift syncopation. Pick-ups were misheard as downbeats in the second and third experiments reported by Gabrielsson (1973), as well as in Sloboda's (1983) experiment. Similarly, Snyder and Krumhansl (2001, pp. 476–477) found that rag-time pieces with pick-ups in both left and right hand elicited the poorest performances from participants in a tapping experiment. These observations suggest that an important cue for metric induction is simply primacy: to assume that early onsets, especially the first onset, are metrically strong. Karpinsky (2012, ¶ 3.4) notes his own tendency to hear the 'downbeats at the beginnings of phrases.' Consistent with this idea, four of the excerpts featuring /-/ displacements also involve

[34] All other participants tapped the alternate interpretation throughout the excerpt.

[35] Only the Gb pitch offers a weak accent, mildly favoring the alternate interpretation.

[36] In general, *Amazing Journey* gave participants more difficulty than other excerpts, perhaps because the excerpt features durations odd attack envelopes, including sounds being played backwards. London describes his own experience hearing a /3+5/ pattern as ♩ |𝅗𝅥 in a $\frac{3}{4}$ metre (with a quarter note pickup) (London, 2004, p. 127)—in some of the unsuccessful trials of *Amazing Journey* participants appeared to be having a similar experience.

hearing the very first onset as the downbeat. As noted above, several 'mysteries' in the experimental observations are also explained by this tendency: the agreement observed on *All My Life*'s consistent interpretation, the 'flipped' hearing of *Ain't My Bitch*'s drum beat, as well as the /3+5/ interpretation of *Amazing Journey*. In two further cases, *All Along the Watchtower* and *Sonata 10*, pickups beginning on weak metrical locations are interpreted not as the downbeat, but as relatively strong beats nonetheless. *Heresy* is the only example from Study 2 wherein participants interpreted the consistent downbeat as a pickup. However, in *Heresy*—as well as *Intermezzo in A*—participants did tend to interpret the first *bass note* as the downbeat.[37]. In total, nineteen of the twenty-four alternate interpretations in Study 2 involve hearing the first onset (or bass onset) as a strong metric position.

The preference to hear early onsets as metrically strong can be seen as a specific application of Lerdahl and Jackendoff's more general 'Strong Beat Early' rule[38]:

> Weakly prefer a metrical structure in which the strongest beat in a group appears relatively early in the group (Lerdahl & Jackendoff, 1983, p. 76).

This rule is given little attention in GTTM—only two sentences are used to clarify the definition and the example given is a rather atypical, cadenza-like Beethoven passage with irregular groupings, suggesting that the authors consider the rule a last resort for strange or ambiguous passages (1983, p. 76).[39] The potential importance of the rule to relatively common, mundane rhythmic figures, such as pickups, is not considered. What's more, their stated definition of the rule specifically includes the word 'weakly,' and their discussion of a final example, in a footnote (p. 336), explicitly states that the Length rule (MPR #5) will outweigh the Strong-Beat-Early rule. In contrast, examples from the second study suggest that Strong-Beat-Early preference can outweigh the Length preference: the most striking example is *All My Life*, but Saint-Saëns' *Symphony 3*, Brahms' *Intermezzo in Eb*, *All Along the Watchtower*, *Caroline No*, and *Amazing Journey* can all be seen as examples of early onsets outweighing long durations.

GTTM's preference rules were not intended as a model of real-time (sequential) listening (Lerdahl & Jackendoff, 1983, pp. 3–4). It seems that in a real-time listening environment the Strong-Beat-Early preference plays a larger role than Lerdahl or Jackendoff's theory suggests. It is plausible that listeners assume that first rhythmic event in a piece of music is metrically strong, and only discard this interpretation if subsequent rhythmic events strongly conflict with it. In Hesselink's words, the initial event creates a strong 'anchor' which requires significant information to be displaced (Hesselink, 2014, p. 73). The Strong-Beat-Early preference is also logical given the statistical learning hypothesis, as the majority of music starts with an onset on a strong beat: Considering the data from Study 1, 316 (63%) of the 500 songs in the Rolling Stone sample, and 469 (63%) of the 739 songs in the McGill Billboard sample, begin with a in-time rhythmic attack on the downbeat. Thus, even a thoughtless application of the Strong-Beat-Early (first onset = downbeat) would get the metric phase correct nearly two-thirds of the time.[40]

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[37] Another widely attested preference is observed in my data: the added weight given to lower pitches (Lerdahl & Jackendoff, 1983, p. 88) The lowest pitch attracts stable, but not necessarily consistent, metric interpretations in *Kate*, *Ride the Lightning*, *Heresy*, *I Robot*, *Pigs*, and both the Brahms *Intermezzi*.

[38] They also refer to the rule as the 'correlation of metre and grouping' (p. 298) and the 'downbeat early' rule (p. 336).

[39] The rule is only referenced (briefly) at two other places in the text body and in one footnote.

[40] Interestingly, if one ignores drum fills (highly idiomatic gestures), approximately 75% of songs begin with an attack on the downbeat (following the drum fill).

A large set of diverse observations in studies 1 and 2, as well as the existing literature, suggest the importance of the Strong-Beat-Early rule. Fortunately, this rule can be expressed as a very clear, testable Strong-Beat-Early hypothesis. Thus, a final experimental study was conducted to test this hypothesis.

Stimuli

A subset of nineteen excerpts from Study 2 study were used—fifteen from the ambiguous excerpts, four from the control excerpts. A single 2–4 measure multi-stable phrase was cut from each excerpt and looped smoothly for approximately fifteen seconds. In the case of *Kate*, two slightly different looped sections were cut—one consisting of the solo piano from the beginning of the song and one which included the drum and bass accompaniment—, bringing the total number of excerpts to twenty. For each excerpt, an altered version was created in which the very beginning of the excerpt was edited—in most cases to remove a pickup. For instance, for the excerpt from *Caroline No*, the single eighth-note tambourine attack was removed from the beginning, such that the first attack was the downbeat. Excerpts which tend to evoke a /-/ displacement, such as *Wake Up* and *She's A Woman*, begin with silence on the downbeat, followed by a first attack on a back/offbeat. In these cases, the alteration involved adding a synthetic kick-drum sound at the point where the downbeat would be, instead of a rest. If the Strong-Beat-Early rule is indeed an important part of metric induction, this alteration should make listeners *more* likely to hear the consistent interpretation of these excerpts. In the case of pieces which do start with an attack on the downbeat, the alteration involved either deleting this beat, causing the edited recording to start on beat two of the measure, or adding a pickup by splicing material from the end of the loop to he beginning. The simplest example of a pick up addition is *All My Life*, where the last ♪ of the measure was copied and pasted at the beginning of the excerpt. If the Strong-Beat-Early rule is an important part of metric induction, these alterations should make listeners *less* likely to hear the consistent interpretation of the excerpt. As a result of these alterations, an 'original' and an 'edited' version of each excerpt were created. Details of the alterations of each excerpt are presented in Table 5. According to the Strong-Beat Early hypothesis, versions of excerpts with downbeats at /0/ should be more likely to evoke the consistent interpretation.

Method

Twenty undergraduate music students at the Ohio State University were recruited as participants. Participants' tapped their metric interpretations on a computer keyboard, using the spacebar key to tap the tactus beat while tapping the downbeat of each measure on the tab key.[41] A metronome drum track was played before each excerpt to establish the tempo and metre (simple duple in all cases except the *Intermezzo in Eb*). Each participant heard the twenty excerpts played in a random order twice (a different random order each time) for a total of forty hearings. Each participant heard both versions of each excerpt, with the version they heard first selected randomly. *A priori*, it seems likely that participants' first interpretation of a piece will influence their interpretation on repeated listenings. If participants interpret the same piece differently on two different hearings, this would constitute especially strong evidence that the edit condition is succesfully influencing participants' experiences.

[41] *beatStation* software was used to play audio and collected tap information (Miron, Davies, & Gouyon, 2013).

Table 5. Description of original and altered versions of excerpts used in Study 3. The 'First onset' column indicates where the first onset in the excerpt occurs, relative to the consistent downbeat. For instance, the original version of *Caroline No* begins as a pickup one +♪ before the downbeat, but the edited excerpt removes this pickup so that the excerpt starts on the downbeat (/0/).

Excerpt	Original first onset	Edited first onset	Alteration
See You	-♪	0	Downbeat insertion
I Wish I Had an Evil Twin	-♪	0	Downbeat insertion (kickdrum synth)
Caroline No	+♪	0	Pickup deletion
Beethoven Concerto 1	+♪	0	Pickup deletion
Good Times Roll	+♪	0	Pickup deletion
I'm Free	+♪	0	Pickup deletion
Intermezzo in Eb	+♪	0	Pickup deletion
Kate	+♪	0	Shift-syncopation truncated
She's A Woman	-♩	0	Downbeat insertion (kickdrum synth)
Ain't My Bitch	+♩	0	Pickup deletion
Ride the Lightning	+♩	0	Pickup deletion
Amazing Journey	+♩.	0	Pickup deletion
All Along the Watchtower	+♩.	0	Pickup deletion
Pigs	0	-𝅗𝅥	Downbeat deletion
All My Life	0	+♪	Pickup insertion
Crazy Little Thing Called Love	0	-♩	Downbeat deletion
Pet Sounds	0	-♩	Downbeat deletion
Sweet Home Alabama	0	-♩	Downbeat deletion
Through the Never	0	-♩	Downbeat deletion

Coding and Results

Data was filtered for steadiness using criteria similar to that of Parncutt (1994, p. 416) and Drake et al. (2000, pp. 8–9).[42] After filtering out unsteady taps, sixty-nine observations had fewer than ten spacebar taps remaining; these observations were discarded from analysis, with the bulk of the discards (thirty-six) being observations of *Amazing Journey*.[43]

Responses to the tactus-beat (spacebar) keystrokes were analysed first: Analysis of the tactus keystrokes is necessary to evaluate the metric interpretation of only the twelve excerpts which feature sub-tactus displacements (♪, 𝅘𝅥𝅯, ♩.). Using criteria similar to Fitch and Rosenfeld (2007, p. 49), spacebar taps were matched to either the offbeat or beat, though in 11% of cases the intended interpretation could not be determined. The results for the twelve pertinent excerpts are shown in Figure 6. As can be seen, there are notable differences in the interpretations of the original and edited excerpts (black versus grey bars). By referencing Table 5 we can see that these differences are exactly as predicted given the edits, and thus consistent with the Strong-Beat-Early hypothesis. For instance, participants nearly always heard the original version of *All My Life* in the consistent interpretation (as they did in Study 2), yet fifteen participants heard the alternate interpretation when the excerpt was edited, interpreting the added pick-up as the downbeat.

Recall that participants heard both versions of each excerpt twice, but with the order (edited or original) randomized. The promising results in Figure 6 are apparent despite the inclusion of data from both first and second hearings. The dashed/solid portions of each bar in Figure 6 divide the bar into observations which were first hearings (dashed) and observations which were second hearings (solid). If you restrict your attention the dashed portion of the bars you can see that, as predicted, the effect of the editing is stronger on first hearings (dashed bars) than over all. Participants tapped different interpretations on their two hearings in 42% of cases. This suggests that editing the beginning of excerpts was enough to change participant's interpretation of the passage, even when they had already heard and tapped successfully to the piece 42% of the time.

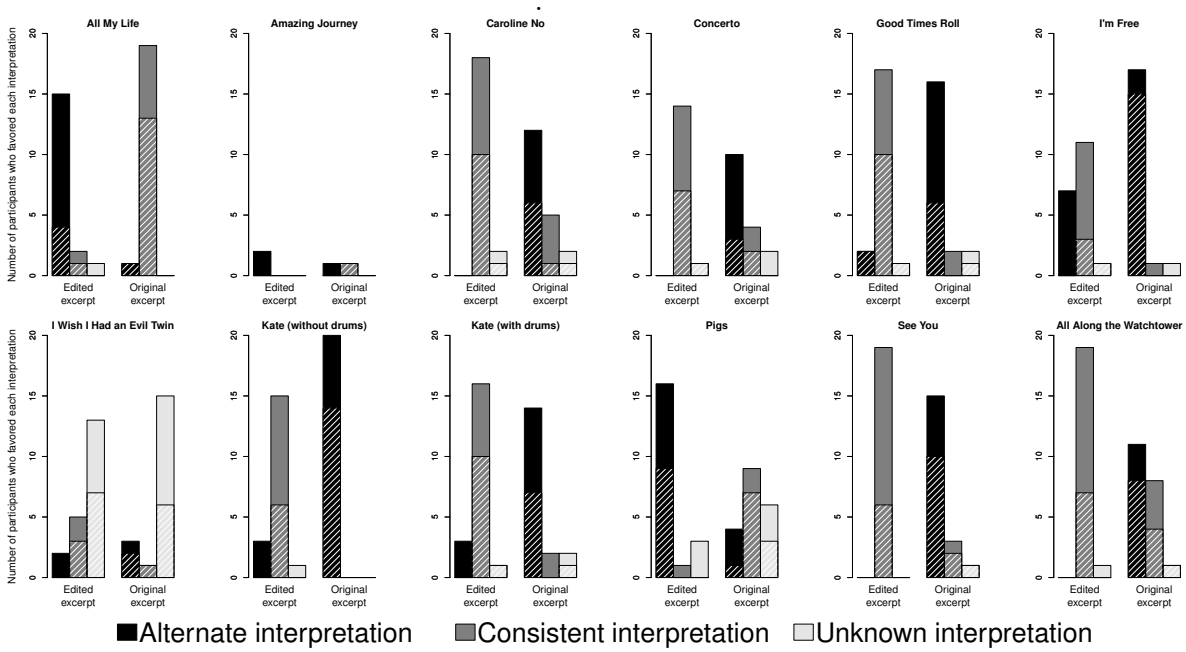
In order to evaluate participants' metric interpretations of the remaining nine excerpts (and the cases of double-time tapping to *I Wish I Had an Evil Twin* and *Pigs*) downbeat taps (tab keystrokes) were analysed. In many cases, participants tapped patterns such as /1 3 1 3/ or /2 4 2 4/, clearly tapping 𝅗𝅥beats as if the metre was $\frac{2}{4}$ not $\frac{4}{4}$. Since, these nine excerpts featured quarter note shifts (no ♩ displacements were used in this study) it seems reasonable to analyse the pieces as if they were in $\frac{2}{4}$. The slow 6/8 metre of the Brahms' *Intermezzo in Eb* was similarly analysed as three, not six. Based on this scheme, Figure 7 presents the interpretations for the remaining nine excerpts.

At a first glance, the results illustrated in Figure 7 are less promising than those in Figure 6, as the difference between grey and black bars is generally less pronounced. However, *Ain't My Bitch* and *Ride the Lighting* do appear to show changes of interpretation dependent on the removal of the pickup—only once was a participant 'faked-out' when these excerpts' pickups were removed. What's more, recall that four of the ex-

[42]Three excerpts—*I Wish I Had an Evil Twin*, *Pigs*, and *She's A Woman* featured many instances of participants tapping at double or half the intended tempo. Similar problems were observed in Snyder and Krumhansl's (2001) experiment. Although these instances complicate the issue of determining what metric interpretation was intended, they still represent steady tapping of a musically relevant beat, and were thus worthy of retention so long as they met steadiness criteria.

[43]Participants found it difficult to tap steadily with *Amazing Journey* in Study 2 as well.

Figure 6. Participants' interpretations of original and altered sub-tactus-displacement excerpts. The height of each bar indicates the number of participants who tapped each interpretation, with black bars indicating the alternate interpretation, and dark grey bars indicating the consistent interpretation—light grey bars indicate uninterpretable responses. For each excerpt, the left set of bars indicates tapping in response to the edited version, and the right set of bars indicates responses to the original excerpt. Dashed portions of each bar indicates data from first hearings.

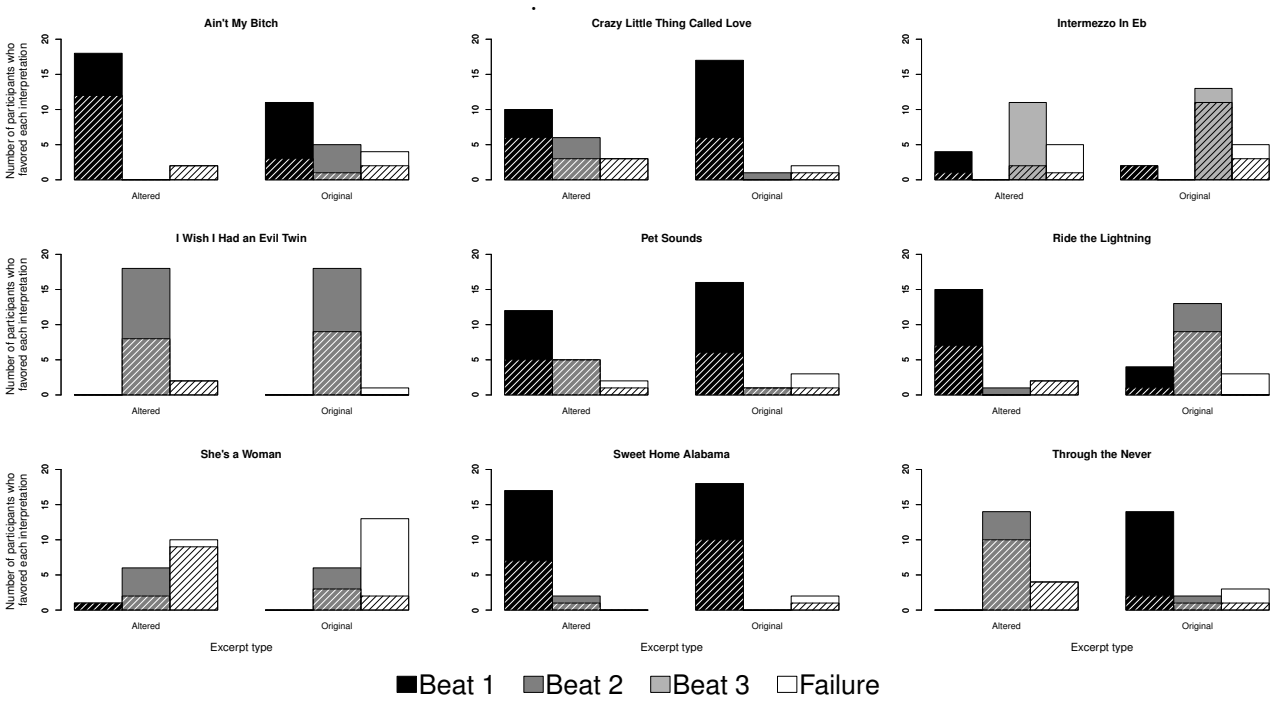


cerpts shown in Figure 7 (*Crazy Little Thing Called Love*, *Pet Sounds*, *Sweet Home Alabama*, and *Through the Never*) were originally selected as unambiguous control excerpts. Despite the supposed unambiguity of these excerpts, three of these excerpts show influences from the edit condition. *Sweet Home Alabama* seems to be particularly resistant to any alternate interpretation; evidently other metric cues in this passage are so strong that the Strong-Beat-Early preference is completely overridden.[44] *I Wish I Had an Evil Twin* and *She's A Woman* also show little sign of influence due to the edit. These excerpts are both /-/ displacements, with a rest on the downbeat followed by a first onset on an off/back beat. Evidently the added kick drum hit edit was not enough to convince participants to hear the consistent interpretation of the downbeat. Finally, the *Intermezzo in Eb* also shows no effect from the edit condition.

Since the musical excerpts used in this experiment are each unique and different, the best interpretation of the results comes simply from examining Figures 6 and 7. However, to formally test the Strong-Beat-Early preference rule and generalize beyond these specific excerpts it is necessary to characterize the results summed across all excerpts and perform a statistical test. For all observations, the participants' responses were recoded as either /downbeat = first onset/ or /downbeat ≠ first onset/. To summarize, 13% of observations were uninterpretable and could not be judged, 65% of observations were consistent with the Strong-Beat-Early rule, and the remaining 22% were inconsistent with the rule. Thus, nearly triple as many observations are consistent with the rule as not. If only first hearings are considered, the ratio is even

[44]This was also, generally, the piece most familiar to participants, which may have made it especially insensitive to editing.

Figure 7. Participants' interpretations of original and altered tactus-displacement excerpts. The height of each bar indicates the number of participants who tapped each interpretation, bar colour indicating which consistent beat is tapped as the downbeat—white bars indicate uninterpretable responses. For each excerpt, the left set of bars indicates tapping in response to the edited version, and the right set of bars indicates responses to the original excerpt. Dashed portions of each bar indicates data from first hearings.



more consistent with the rule, at 68% versus 19%. A mixed-effect logistic regression model was constructed, predicting the interpretation (Consistent or Alternate) using hearing order (first or second) and the Strong-Beat-Early rule as fixed predictors, with random intercepts for Song. The effect for hearing order was not significant ($\chi^2(1) = 0.02$, $p = .87$). However, the Strong-Beat-Early rule is a significant predictor ($a = -1.673$, $b = 3.198$, $\chi^2(1) = 205$, $p < .00001$). The estimated slope for the Strong-Beat-Early rule—3.19—suggests that the odds of a listener tapping the consistent interpretation are twenty-four times greater when the downbeat is the first onset than when it is not.

Conclusions

This paper reports the results of three empirical studies regarding the perception of metrically ambiguous musical passages known as *metric fake-outs*. The results of the first study, suggest that, for any particular musically trained listener, approximately one in sixty popular songs evoke fake-outs, with as many as one in five songs containing other, more fleeting, examples of metric ambiguity. The second study documented fake-out experiences in a larger group of listeners, attesting to the reality of metric ambiguity both within and between listeners, in conflict with claims that metric ambiguity never occurs (Agawu, 1994). What's more, the data shows that metric ambiguity can arise even in response to dynamically and temporally nuanced performances by professional musicians. Different listeners were frequently found to interpret the same music differently; in fact, responses to several excerpts were split nearly evenly between two interpretations. Consistent with the results of Vazan and Schober (2004), listeners were not found to favor the consistent interpretation, even when it became apparent to them. Finally, listeners were able to consciously control their metric interpretation to some extent, although success was highly dependent on the nature of the musical passage and the skill of the listener. Throughout, no concrete link between listeners' musical experience and their choice of metric interpretations was found. Given the eclectic and varied listening habits of modern listeners it may be impossible to find listeners whose musical listening experience (and the implicit knowledge they gather from it) differs enough to predictably influence their metric interpretations. For instance, most classical-music listeners have nonetheless been amply exposed to the syncopations of rock/pop music.

Many observations in Study 2 support the importance of theoretical *preference rules* for metric induction, including preferences to place longer, lower notes in strong positions and to minimize syncopation. However, a number of data points are poorly explained, or even conflict, with existing preference rules. More controlled experimental studies are needed to isolate the independent effects, and interactions, of various preference rules and the implicit knowledge they represent. Study 3 presents one such experiment, intended to test the importance of the Strong-Beat-Early rule—the general preference to hear the first events in a musical piece as metrically strong. The results of the experiment are consistent with the Strong-Beat-Early rule: The simple rule-of-thumb assumption that the first onset is a relatively strong beat seems to effectively predict listeners interpretations in a majority of listening situations. In fact, participants tapped a metric interpretation consistent with the first onset being the downbeat over 70% of the time. Data from Study 1 indicates that this is roughly consistent with the proportion of popular songs which begin with an onset on the downbeat. A statistical model estimate suggests that, overall, listeners are

twenty-four times more likely to tap an interpretation wherein the first onset is the downbeat than not. Considering that this effect was evident even with two of the ostensibly unambiguous control excerpts, Lerdahl and Jackendoff's Strong-Beat-Early rule might be more strongly worded: perhaps 'weakly prefer' or 'relatively early' ought to be changed to 'strongly prefer' and 'early, or at the beginning' respectively. Still, we should not overestimate the importance of this effect. The excerpts in studies 2 and 3 were not a random sample of music: the excerpts were selected specifically because they were known to be metrically ambiguous *a priori*. It may be that only when other musical cues give insufficient information to determine the metre that listeners resort to the Strong-Beat-Early rule. One example in the study, *Sweet Home Alabama*, was heard in the consistent interpretation no matter how it was edited. Still, the interpretation of several other control excerpts—which were *a priori* considered to be unambiguous—was influenced by editing, suggesting that this rule may play a role even in the interpretation of relatively unambiguous passages.

The results of the studies presented here suggest that the perception of metre in music at large may actually be more variable than most musicians/theorists would tend believe. Furthermore, participants in this study all had some musical training, so the variability in metric experience that occurs among non-musicians is possibly far greater than the variability observed here. In general, it seems that musicians and composers should not assume that the metric interpretation of their music is obvious to listeners. Even passages that seem metrically unambiguous to an expert may be evoking a variety of different metric interpretations; as was the case with Beethoven's *Sonata 19* in Study 2. We may feel that our intended metric structure is clear, but only by asking a listener, who is unfamiliar with the piece, can we be sure. Of course, this ambiguity is not necessarily a negative feature—rather the ability of listeners to interpret music in their own personal way may be a key part of the musical experience (Guck, 2006).

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