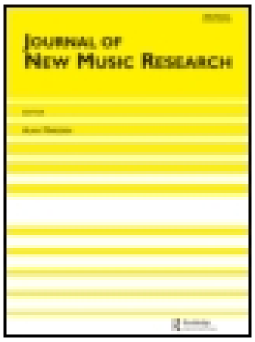

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Mapping timing and intensity strategies in drum-kit performance of a simple back-beat pattern

Guilherme Schmidt Câmara, George Sioros and Anne Danielsen

RITMO Centre for Interdisciplinary Studies in Rhythm, Time and Motion, University of Oslo, Oslo, Norway

ABSTRACT

We explored how drummers express a 'back-beat' pattern with different timing styles (laid-back, on-beat, pushed) via stroke onset and intensity features. Based on hierarchical clustering analyses and phylogenetic trees, we found three main strategies: (1) 'general earliness/lateness', where most instruments are consistently played earlier/later in time relative to a metrical grid; (2) 'early/late flam', where at least one instrument is played as a flam; and (3) 'ambiguously early/late compound sound', where in a dyad, one instrument is played synchronously with the grid, and the other early/late. Intensity strategies were not used uniformly to exclusively distinguish between laid-back/pushed and on-beat timing.

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KEYWORDS
Rhythm; groove; timing; microtiming; drum performance; intensity

1. Introduction

Musicians and scholars take it for granted that expert performers can change the timing style or 'feel' of a pattern by subtly altering the timing of onsets so as to deviate from their fellow musicians, an external beat reference or their own internal pulse (Butterfield, 2006; Câmara, 2016; Danielsen, 2018; Danielsen et al., 2015; Friberg & Sundström, 2002; Iyer, 2002; Kilchenmann & Senn, 2011; Skaansar et al., 2019). Such deviations include playing slightly early ('pushed') or slightly late ('laid-back'). In drum-kit performance, drummers are purportedly able to control the degree of onset timing asynchrony between the various constituent instruments of the drum kit, which may further contribute to the overall 'feel' of a given drum groove (Câmara & Danielsen, 2018; Danielsen, 2010; Monson, 1996). Manipulating dynamic expression via stroke intensity is considered a key aesthetic device of drum performance in general (Dicianni, 2014; Dylan, 2019; Jordan, 2009; Räsänen et al., 2015) and has recently been hypothesised as an additional modulating factor in the perceived timing of strokes in performance (Câmara et al., 2020b; Danielsen et al., 2015).

Typical reported values of microtiming onset asynchronies in groove-based performances range from zero milliseconds (no displacement) to fifty milliseconds or more, depending on instrument, tempo, and genre (Câmara, 2016; Fujii et al., 2011; Hellmer & Madison, 2015; Senn et al., 2016). As to whether one can perceive such asynchronies, findings from psychoacoustic studies with pure tones or clicks have suggested that thresholds can be as low as two milliseconds (Friberg & Sundberg, 1995; Hirsh, 1959; Lauzon et al., 2020; Zera & Green, 1993), and that the threshold for discerning the temporal order of sounds (that is, correctly identifying which tone comes first/second) is generally higher, at around twenty milliseconds (Hirsh, 1959). Most onset asynchrony and/or intensity discrimination tasks tend to be conducted in relatively simple listening contexts, usually involving only two sounds at a time of the same instrument/tone type, presented as isolated rhythmic layers without external timing reference sounds. Real musical performances, on the other hand, represent rhythmically complex contexts for both performers and listeners. Drum-kit performances alone tend to contain a minimum of three separate rhythmic layers (kick, snare, and hi-hat) and at least one or two additional accompaniment rhythmic layers in ensemble settings. Moreover, instrumental sounds tend to be complex and have overlapping spectra and/or unequal duration or loudness, all of which can lead to masking effects of various degrees that likely increase these thresholds. As a consequence, music performance studies have suggested that the threshold for the detection of asynchrony between two sound events in a musical groove context is larger, at around twenty to thirty milliseconds (Butterfield, 2011; Câmara, 2016; Clarke, 1989). Studies have also revealed

CONTACT Guilherme Schmidt Câmara g.s.camara@imv.uio.no RITMO Centre for Interdisciplinary Studies in Rhythm, Time and Motion, University of Oslo, Postboks 1133 Blindern, Oslo 0318, Norway

interactions between perceived timing and intensity of events in performance. Goebl and Parncutt (2002) found that the relative perceptual salience of asynchrony in tone dyads depends on both relative intensity and magnitude of onset asynchrony. Tekman (2002) found that it was easier to correctly identify a tone as being late in relation to another tone when it was both positioned late in terms of onset timing and played with greater intensity, as opposed to positioned late but played at an equal intensity.

As to production, findings from several instructed-timing experiments have shown that expert rhythm-section musicians – guitarist and bassists (Câmara et al., 2020a) as well as drummers (Câmara et al., 2020b; Danielsen et al., 2015; Kilchenmann & Senn, 2011) – are able to play stroke onsets of a given pattern under different laid-back and pushed timing style instructions significantly earlier and later than an instructed on-beat performance, respectively, in a systematic manner. Regarding drummers, the effect of timing reference stimuli has also been tested by Câmara et al. (2020b) and found to affect average onset timing in terms of how closely they were able to synchronise with the reference sounds. Specifically, shorter metronome sounds with extremely fast attacks led to greater negative mean asynchrony ('NMA')–that is, systematically early onset timing–than that related to wider bass and guitar sounds with relatively slower attacks. This is possibly due to the delaying effects of slower attack and longer duration on perceptual centres ('P-centers'), understood as the perceived moment of rhythmic occurrence of sounds (Morton et al., 1976), which is distinct from the physical onset (beginning) of sounds (Danielsen et al., 2019). Since the magnitude of onset asynchronies in performances can often be small, Danielsen et al. (2015) hypothesised that musicians further manipulate sound features shown to interact with timing at a perceptual level, such as duration, spectral centroid (SC), and/or intensity, in ways that can increase the detectability of timing asynchronies when playing with an intentionally laid-back or pushed timing feel. Câmara et al. (2020a) found that, on average, guitarists tended to play laid-back strokes with a longer attack, longer total duration, and higher SC, whereas bassists tended to play pushed strokes with greater intensity. In a snare drum performance experiment with ten drummers, Danielsen et al. (2015) found that drummers tended to play laid-back strokes on the snare louder than on-the-beat and pushed strokes. Moreover, in a study with a full drum kit (kick, snare, and hi-hat) and twenty-two drummers, Câmara et al. (2020b) replicated this result but also found that average snare intensity tended to be greater in both the pushed and laid-back conditions. The same intensity pattern was also present for the hi-hat.

In these previous drumming studies, participants were instructed to play with a certain timing feel and the investigative focus was on comparing average statistical trends of onset timing or intensity between timing style conditions across entire groups of drummers. While enlightening, this approach inadvertently obfuscates the diversity in individual timing and sound strategies that is present within these groups (see, for example, Dahl, 2004), since averages represent first and foremost statistical tendencies rather than real performance strategies as such. Though reported group trends can inform us that in laid-back and pushed performances drummers tend to delay and anticipate all the drum-kit instruments relative to the grid, in reality, drummers likely develop different individualised strategies. For example, to achieve a laid-back performance, a drummer may simply play all the drum strokes late relative to the grid, but 'in sync' with each other. A different strategy might involve focusing on just delaying one element in the drum kit, producing extended inter-instrument 'flams' around the metrical beat position, consisting of two near-simultaneous strokes on either one or two instruments. Furthermore, the same drummer may choose to dynamically accentuate either the first or the second stroke of the flam dyad, respectively diminishing or enhancing the overall laid-back character of the late drum element via acoustic masking.

In this study, we are interested in identifying the different strategies that drummers use when playing laidback and pushed. Accordingly, our research question is: How do musicians differentiate laid-back or pushed from on-beat performances? We analyze drum performances from a previously conducted experiment (see [2.1]) in order to map the strategies present at the individual participant level and categorise the different archetypical ways in which drummers may express the same simple rhythmic pattern in laid-back, on-beat, and pushed performances. We limit our analysis to the onset asynchrony among the instruments of the drum kit themselves and in relation to the metrical reference grid, exploring the extent to which drummers employ consistent onset strategies and also choose different instruments in the rhythmic pattern to generate on-the-beat, laid-back, and pushed performances respectively. We also explore the degree to which drummers adopt consistent strategies in using intensity to discriminate between the three different timing styles (pushed, laid-back, and on-beat).

Central to our analysis are relative frequencies with which the different onset asynchronies and intensities occur in the participants' performances. A hierarchical classification of the performances based on their onset and intensity profiles reveals specific strategies that are summarised as *onset and intensity archetypes.* These

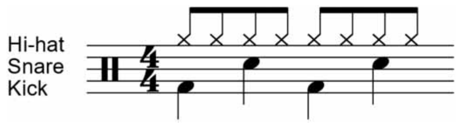

Figure 1. Basic 'back-beat' pattern in 4/4 meter (kick on beats 1 and 3, snare on beats 2 and 4, and hi-hat on all straight 8th notes).

capture the main characteristics of the clusters in a symbolic form. Finally, a visualisation of the clustering result as phylogenetic trees provides an overview of these strategies and how they are related. The rest of the article is divided into three sections. In [2.1] we describe the experimental data we used. In [2.2] we describe the general methodology, including the onset [2.2.1] and intensity [2.2.2] features more closely, the clustering method [2.2.3], and the archetypes [2.2.4]. Then we present the results [3] and discussion [4] of our analysis; in the last section [4], we summarise our findings and offer concluding remarks.

2. Materials and methods

2.1. Experiment data

The performances analysed in this article were collected as part of the project reported in (Câmara et al., 2020b). Twenty-two male drummers aged twenty-two to sixty-four ($M = 36$, SD $= 11$) participated in theexperiment.[1] All of them were active part-time or full-time musicians familiar with at least one groove-based performance tradition (jazz, funk/soul, hip-hop, rock, or reggae), and they all had between four and forty years of professional performance experience ($M = 16$, SD $= 11$).

The participants were instructed to play a standard 'back-beat' pattern (see Figure 1) at a medium tempo (96 bpm) to two timing reference tracks composed of a quarter note stream of:

(1) woodblock sounds (beats 1–4) [condition: metronome], and
(2) bass (single notes, beats 1 and 3) and guitar sounds (chords, beats 2 and 4) [condition: backing track],

In 3 different timing style conditions:

(1) a 'laid-back' manner [condition: laid-back],
(2) a 'pushed' manner [condition: pushed],
(3) an 'on-beat' manner [condition: on-beat].

[1] Two participants' data sets (coded as '*e*' and '*f*' in this study) were excluded from the analysis: one participant suffered technical issues during the recording process, and the other was deemed to have not understood the task based on responses from a follow-up interview.

Each timing style condition trial lasted for approximately 67.5 s, and participants began to play as soon as they had entrained with the timing reference track. This resulted in approximately two-hundred hi-hat, fifty snare and fifty kick-drum strokes captured per performance. Recordings from AKG C411 contact microphones (AKG, Austria) placed on the top/front skins of the kick and snare and on the top cymbal of the hi-hat were used for the onset and intensity feature analyses. The five first bars of each recording were excluded from the analyses, because we assumed it might take a few repetitions of the pattern to entrain with the reference stimuli for some drummers. All of the audio examples presented were mixed down using signals captured from dynamic microphones (Beta 52 and SM57; Shure, USA), where the original intensity differences between timing style conditions were preserved. For further details regarding the set-up, procedure, and materials used in the experiment, see Câmara et al. (2020b) and Câmara (2021).

2.2. Method

The analysis of the performance recordings consists of three main steps, following the methodology used in Sioros et al. (2019):

(1) the extraction of features relevant to the onset timing and intensity of the drum strokes,
(2) the clustering of recordings based on the similarities of their features, and
(3) the construction of archetypes that summarise the main characteristics of each cluster.

The first step involved the extraction of several Boolean features for each 4/4 measure from the detected stroke onsets and intensities of each drum-kit instrument, calculated using the *mironsets* and *mirrms* algorithms from the MIR Toolbox [version 1.8] (Lartillot et al., 2008). The majority of these features test whether a certain drummer performed a drum stroke differently in the laid-back or pushed timing style condition than in the on-the-beat condition. In this way, the on-beat performance of each drummer serves as an individual reference for the different timing and intensity aspects of the drum strokes. For instance, one feature tests whether drummers performed a particular laid-back or pushed snare stroke louder than their average on-beat stroke.

Moreover, all Boolean features depend on various tolerance thresholds that are obtained for each drummer individually from their on-beat performances, which serve as a 'tailored scale' for comparing the other timing instructions for the same drummer. It is important to note that the design of the features does not seek to directly compare recordings among the different drummers. Instead, our focus is on their differences from their respective on-beat performances. As such, on-beat performance features do not exhibit great differences among drummers, with the exception being those describing the stroke onset relation between instruments (whether inter-instrument asynchronies are present or not) and the onset of the snare and kick drums relative to the grid (early/late). This is a direct consequence of our research question, 'how do musicians differentiate laid-back or pushed from on-beat performances?'

The Boolean features (taking the values 0 or 1) are averaged over the duration of the respective performances, yielding the frequency with which each feature is found in the performance (values in the range 0% to 100%). The set of the averages of all features forms the performance's onset and intensity profile. The averages are calculated at the bar level for each of the four beat positions of the 4/4 m in turn (see Figure 2 for an example).

Because the profiles represent frequencies of occurrence of the various features, they describe how consistent each performance is, but they supply no information about the magnitude of the various quantities involved in their calculation. For example, the snare loudness feature calculates the percentage of the bars in which a snare stroke was performed louder on average than in the on-beat condition but does not indicate how much louder the strokes were. A percentage closer to 100% corresponds to a highly consistently different performance from the on-beat condition, while a percentage closer to 0% is characteristic of a performance that differed only sporadically. A detailed description

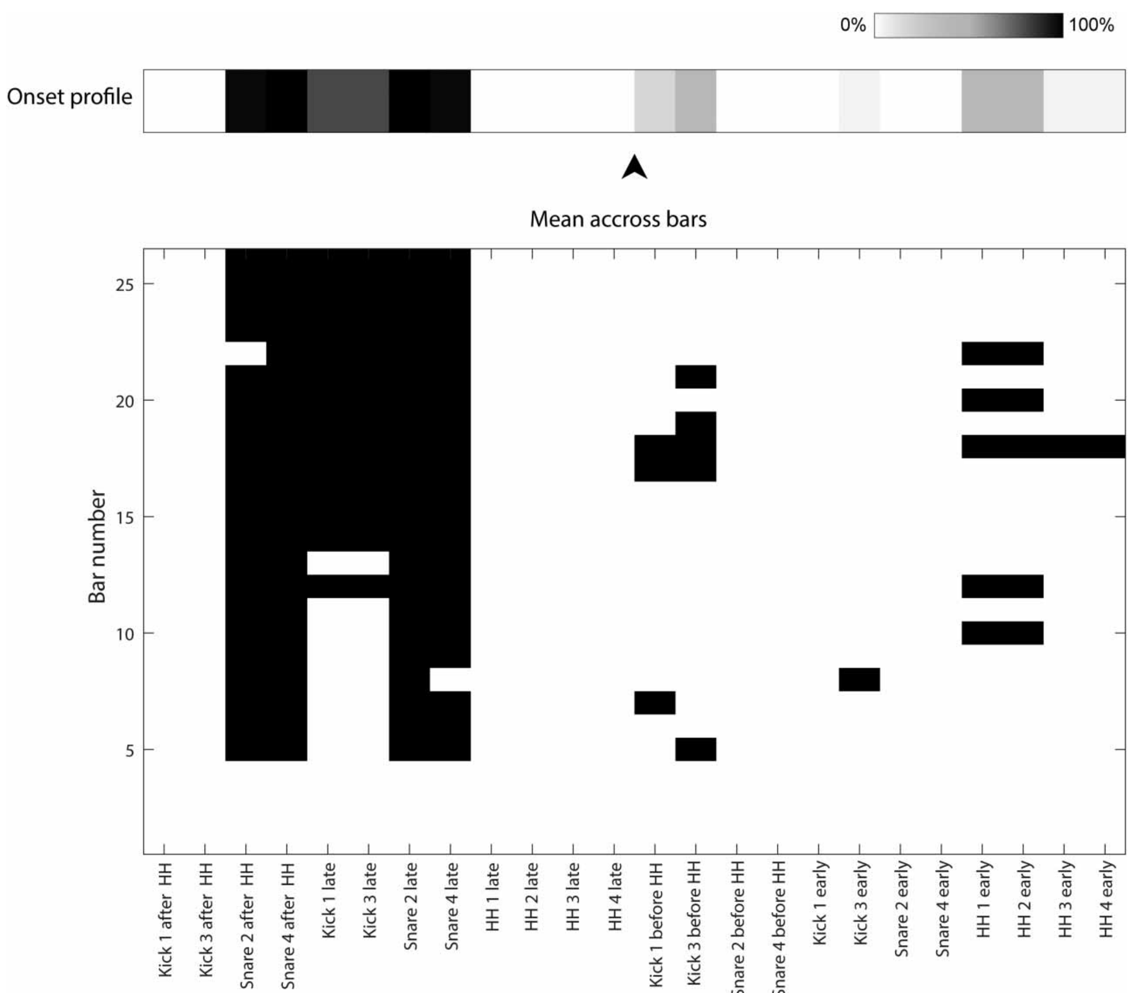

Figure 2. Example of feature profile calculation for the laid-back performance of participant a playing along to the metronome reference. The bottom graph shows the twenty-four onset Boolean features for each bar of the recording. The feature profile (top graph) is calculated by averaging the Boolean features (0 or 1) across all bars of the recording, resulting in their probabilities or frequency of occurrence (0 to 1). Note: HH = hi-hat.

of the Boolean features, the corresponding thresholds, and the feature profiles is given in subsections [2.2.1] and [2.2.2].

To identify clusters of performances that have similar features, a hierarchical clustering algorithm is applied on the timing and intensity profiles of the recordings. Finally, timing and intensity archetypes are created for each cluster, based on the profiles of the recordings belonging to them. The clustering algorithm and the archetypes are described in subsections [2.2.3] and [2.2.4], respectively.

Regarding thresholds, analytical comparisons of produced onset asynchrony and intensity differences in drum-kit performances must be approached with the caveat that heuristic auditory thresholds derived from simple listening contexts may not apply directly to ecological situations. That is, whether events are heard as late/early or soft/loud in a laid-back or pushed performance depends on a number of subjective factors, including, in particular, (1) the rhythmic context (e.g. number of layers, which layer is the foreground), (2) the individual performer's acuity in discriminating onset asynchrony and intensity (see Frane & Shams, 2017), and (3) the performance context. In comparison, produced timing (i.e. the actual chronological timing of events relative to an independent grid) can be measured more objectively, though the values obtained depend on the measurement tools used. For the comparative analyses in this study then, rather than rely on previous heuristic thresholds to determine whether onset asynchrony and intensity features are categorically present between performances with different timing styles, we use thresholds based on measurements of individual participants' produced onset and intensity values (see subsections [2.2.1] and [2.2.2]).

2.2.1. Onset features

The onset features cover micro-level temporal relationships between instruments performing the same beat, as well as all instruments' temporal relationships to the 4/4 grid. They fall into two main categories:

(1) inter-instrument microtiming relationships – that is, whether the kick or snare drum strokes were performed simultaneously with or asynchronously in relation to the hi-hat strokes; and
(2) kick, snare, and hi-hat stroke location in relation to the metrical grid – that is, whether they were late or early.

The timing features form pairs of mutually exclusive Booleans, meaning that a drum stroke can be either early or late but not both, and, similarly, that a kick or snare stroke can be either before or after a coinciding hi-hat cymbal but not both. Although the features of a given pair cannot both be *true* at the same time, they can both be *false* – for example, when a drum stroke is neither late nor early. Table 1 summarises the timing features.

The first category consists of four pairs of inter-instrument relations. For each of the four main quarter-note beats, two features test whether the respective kick or snare occurs before or after the coinciding hi-hat stroke. The tolerance with which two coinciding drum strokes are considered synchronous or not is based on the variability of the inter-onset-interval (IOI) between the same instruments in the on-beat performance. For each drummer, we calculated the standard deviation of the inter-instrument IOIs of the strokes at each of the four beats, then took the synchronicity threshold as the maximum of these four values multiplied by two. The rationale for this approach is that any drum stroke produced at a value of two standard deviations behind or ahead of a given tolerance threshold range (that is, located about 95% outside of the mean stroke distribution of the on-beat performance) is considered to be intentionally early or late, respectively, rather than occurring due to error or chance.

The second category of onset-timing features describes the relation of the three instruments to the metrical grid. For each of the four quarter-note metrical positions, we test whether the two instruments in that position are late or early relative to the expected timing of the beat (four features in total). These features depend on two parameters: the location of the metrical grid and the tolerance threshold with which the instrument strokes are considered late or early. Although the drummers performed to the same metronome and backing track stimuli, the exact location of the perceived metrical grid – that is, the subjective grid with which each drummer operates – may differ from one drummer to another. It has been repeatedly observed that individuals tend to exhibit NMA (systematically early timing) when synchronising in an on-beat manner to short metronomic stimuli with fast attacks (Repp & Su, 2013) and instrument performance tasks (Câmara et al., 2020b; Fujii et al., 2011). Furthermore, P-centre studies show that the rhythmic moment of occurrence in longer instrumental sounds with relatively slower attack times, such as those of the Backing Track, tends to be perceived later in relation to onsets (Danielsen et al., 2019) and also lead to lower NMA in drum synchronisation tasks Câmara et al. (2020b).

Since both NMA and P-centre values can vary greatly from one individual to another, we chose to calculate a subjective metrical grid for each individual drummer independently. The hi-hat is widely assumed to be the main timekeeper of the drum kit, and it is most closely

Table 1. Summary of the twenty-four onset-timing features.

Instrument	Description	Thresholds / References
Kick on Beat 1 Snare on Beat 2 Kick on Beat 3 Snare on Beat 4	Late/early relative to the hi-hat cymbal # of features = 8 (2 features per quarter-note position)	$Threshold = 2 \times \max_{k=1}^{4} \{STD^{j}_{On-beat}(IOI\ at\ beat\ k)\}$ Reference: *NA*
Kick / Hi-hat on Beat 1 Snare / Hi-hat on Beat 2 Kick / Hi-hat on Beat 3 Snare / Hi-hat on Beat 4	Late/early relative to the metrical grid # of features = 16 (2 features per quarter-note position × 2 instruments)	$Threshold = 2 \times STD^{j}_{On-beat}(HiHat)$ Reference: $Metrical\ grid = \mathrm{mean}(HiHat_{On-beat})$

Note: *STD* = standard deviation, *IOI* = inter-onset interval.

and consistently synchronised with external grid reference stimuli (Câmara et al., 2020b; Fujii et al., 2011). The locations of the subjective metrical grid were thus calculated for each drummer as the mean difference of the hi-hat stroke onsets from the location of the Metronome or Backing Track grid in their on-beat performances. As a consequence of this approach, hi-hat strokes in the on-beat performances (but not laid-back or pushed) will never be consistently before or after the beat, but snare/kick strokes still may. The tolerance threshold from which any instrument stroke is considered early/late in a respective laid-back or pushed performance was further calculated as the standard deviation of that mean difference multiplied by two.

Overall then, the multiple timing features encoded in the timing profiles (and corresponding archetypes; see section [2.2.4]) belong to two broad categories: (1) timing relations between two instruments, and (2) timing relations between an instrument and the metrical grid. It is to be noted that features from these categories are not mutually exclusive, rather the characterisation of the timing in each category is based on thresholds that are independently determined. Furthermore, the onset distance between any two instruments is independent of their distance from a corresponding grid point. For instance, a kick drum and a hi-hat cymbal may be close enough to be considered synchronous, while the hi-hat cymbal may be within the distance threshold from the grid, but the kick not. Various such examples can be found in the onset results section [3.1] classified under the '*ambiguously early/late compound sound*' archetype category.

2.2.2. Intensity features

The intensity features cover all instruments' intensities on notes falling on the 4/4 beats. Each intensity feature tests whether a drum stroke is performed louder or softer in relation to the corresponding average stroke in the on-beat recording by the same drummer, and the intensity features form mutually exclusive pairs (louder/quieter). There are eight such pairs (a total of sixteen features) corresponding to the four quarter-note positions of the 4/4 m and the three instruments. They depend on two parameters that are calculated independently for each of the three instruments: a reference intensity level and a tolerance threshold. The reference level is calculated as the mean sound-pressure level (SPL) value in the respective on-beat recording. The intensity threshold level is based on the variability of the SPL value and calculated as the standard deviation multiplied by two, and any stroke intensity produced above or below this threshold range is considered to be intentionally louder/softer rather than due to error or chance.

2.2.3. Hierarchical clustering

To identify groups of performances that implemented distinct strategies to achieve the instructed timing styles, we used hierarchical agglomerative clustering on the performance profiles. Agglomerative algorithms successively join neighbouring data points based on a similarity metric to group them together and organise them in tree structures. To create clusters of similar points within a tree, we employed a method initially developed in the field of bioinformatics and ecology called similarity profiles (SIMPROF) (Clarke et al., 2008). SIMPROF is a top-down method that applies a series of permutation tests on an existing tree to decide whether each branch of the tree has no internal structure and therefore is homogenous and should not be further divided into sub-branches. In this way, clusters are formed when the combination of onset relations found within a branch of a tree cannot statistically be distinguished from accidental differences between performances. We used the SIMPROF implementation for Matlab found in the Fathom Toolbox (Jones, 2017: see also Sioros et al., 2019 for a more detailed discussion of this algorithm). This method allows for the further exploration of the results and the relations between clusters through phylogenetic visualisations.

For the agglomerative algorithm, we used the 'unweighted group average' linkage criterion (UPGMA). As a distance metric between recording profiles, we used the average distance (equation 7.34 of Legendre & Legendre [2012]) – that is, the Euclidean distance divided by the number of dimensions. For the SIMPROF permutation test, we used the following parameters: 10,000 iterations, alpha = 0.025, tolerance = 0.0025, and we progressively adjusted the probability values for multiple simultaneous tests (Bonferroni correction [loc. cit., 745]).

2.2.4. Archetypes

To summarise the general characteristics of each cluster, we computed onset and intensity archetypes by averaging the probabilities of the features of the members of each cluster. As the two kick strokes and two snare strokes did not exhibit great differences per measure, the four quarter notes were grouped into two groups, downbeats 1 and 3 and upbeats 2 and 4. The mean probability values were further reduced to three levels: (1) features consistently present in the performance (> 60% of the time), (2) features less consistently present but showing a frequent tendency (40–60% of the time), and (3) features consistently not present (< 40% of the time).

An important aspect of our analysis is that it is driven by the collected data and does not assume any a-priori clusters or archetypes. The clusters are formed from the differences in the probabilities of the various features in the performances and are statistically tested by the SIMPROF method. After clusters have been formed, probabilities within each cluster are averaged so that only similar performances contribute to each average. Finally, the averages are 'quantized' to keep only the three levels described above. In this way, the resulting archetypes reduce the onset and intensity relations to broad categories and summarise in a visual and interpretable way the strategy followed within each cluster.

In the onset archetype visualisations (see Figure 3), the colour of an instrument symbol, indicates earliness (green), lateness (red), or on-beatness (white) relative to the grid, whereas the colour *intensity* represents the frequency of earliness/lateness, either < 40% (no colour), 40–60% (light), and > 60% (dark). The presence of inter-instrument asynchrony is represented by horizontal displacement between two instrument symbols. Less than 40% frequency of such displacement is treated as no displacement, whereas 40–60% is indicated with dashed lines and more than 60% with solid lines. In addition, the degree of horizontal displacement of the mid-point between two concomitant instruments relative to the grid line symbol indicates earliness (off-centre left), lateness (off-centre right), or on-beatness (centre) *relative to the grid*. To interpret these archetypes, we may look at a hypothetical example of laid-back performance. Figure 4 shows an onset archetype where, compared to an on-beat performance, the hi-hats on metrical positions 1 and 3 (left) were on-beat and the kick strokes showed a tendency to be late in relation to the grid with a frequency

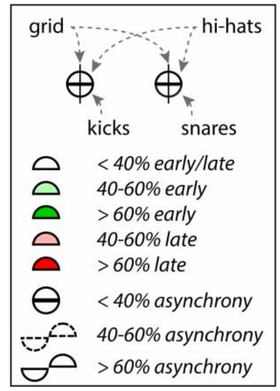

Figure 3. Onset archetype key explanation.

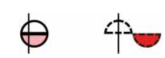

Figure 4. Example of an onset archetype.

of 40–60%, indicated by the light red colour and the off-centre positioning of the grid line. However, kick and hi-hat were synchronous relative to one another (that is, no inter-instrument asynchrony was present), indicated by no horizontal displacement between the instrument symbols. As for the strokes on metrical positions 2 and 4 (right), the hi-hats were synchronised (that is, neither early nor late) with the grid, indicated by the white colour and centre positioning relative to the grid line – while the concomitant snares were consistently late (> 60%), indicated by the red colour and displacement to the right of the grid line. In addition, the snares were played late enough relative to the hi-hats so frequently (40–60%, indicated by dashed lines) as to comprise true inter-instrument asynchronies.

In the intensity archetype visualisations (see Figure 5), a downwards/upwards arrow above an instrument symbol indicates quieter/louder intensity, respectively, in laid-back and pushed compared to on-beat performances with a frequency of either < 40% (no arrow), 40–60% (single arrow), and > 60% (double arrow). Figure 6 shows the corresponding intensity archetype of the same above-mentioned hypothetical performance, where, compared to the on-beat performance, from left to right, the kicks were frequently quieter (40–60%, single downwards arrow), the snare intensity remained the same (neither louder nor quieter > 40%, no arrow), but the hi-hats were played consistently louder (> 60%, double upwards arrow).

A detailed explanation of the visualisation of the onset and intensity archetypes can be found in Figures A1and A2, respectively, in Appendix A.

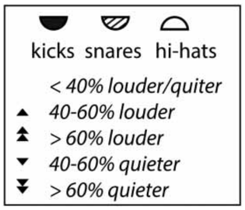

Figure 5. Intensity archetype key explanation.

Figure 6. Example of an intensity archetype.

3. Results and discussion

The timing and intensity features of the recordings are presented in four matrices (Figures 36 in Appendix A) that correspond to onset and intensity features in the two timing-reference conditions, that is, metronome and instrumental backing.

In Figures 7–10, we present phylogenetic visualisations of the same clustering results as unrooted similarity trees. The length of any single branch in the trees corresponds to the average 'dissimilarity' between the performances of the two clusters it connects and is calculated as the average difference of the corresponding feature profiles of the performances. An important characteristic of all four clusterings is the similarity and proximity of all on-beat performances, which partly reflects the design of the feature extraction process (see sections [2.2.1] and [2.2.2]). The distance of the other performances from the on-beat clusters, on the other hand, is an interesting aspect of the trees and provide information in terms of their differences from the on-beat performances. The archetype illustrations assigned to the various clusters reflect their average tendencies and highlight the main elements of each cluster.

In the following sections [3.1] and [3.2], we present the main findings of the clustering of onset-timing profiles and intensity profiles, respectively.

3.1. Onset

3.1.1. Metronome (OM)

The classification of the onset profiles from the metronome condition (OM) shows that the majority of the laid-back and pushed performances form separate homogenous clusters (see tree Figure 7 and matrix Figure A3). As expected, the purely laid-back clusters are generally characterised by some form of late timing in relation to the musicians' perceived grids, and the pushed ones, by early timing. However, the analysis reveals that the drummers utilised a variety of distinct strategies to express a given timing feel by focusing on different grid and inter-instrument onset asynchrony relationships.

Laid-back: 19 out of the 20 laid-back performances are found in six purely laid-back clusters, that is, clusters OM*2*, OM*6*, OM*9*, OM*10*, OM*14* and OM*15* in Figure 7.

Laid-back cluster OM*14* was the largest pure laid-back group, characterised by a '*general lateness*' whereby all of the instrument strokes (kicks, snares, and hi-hats) were played consistently later relative to the grid (> 60%), and in a synchronised fashion relative to each other (that is, there was no inter-instrument asynchrony). The distance between this laid-back cluster and the on-beat clusters was the greatest in the tree. Three performances ('*r*', '*l*', '*q*') seem to split off as a separate sub-branch of this cluster, and the matrix (see Figure A3) reveals that they display a further tendency to play the kicks on downbeats 1 and 3 asynchronously early in relation to the hi-hats (a sort of hybrid '*general lateness + early kick flam*' strategy).

Laid-back cluster OM*10* in Figure 7 is characterised by a '*late snare flam*' approach, an archetype where all instruments are in sync with the grid except for the snare strokes, which are played consistently late relative to both the grid and the hi-hats. The late snare strokes create distinct flams due to the onset distances between hi-hat and snare. Clusters OM*2* and OM*9* are both characterised by a subtler form of lateness involving an '*ambiguously late compound sound*' strategy, whereby two instruments are slightly displaced but still form a compound sound where one instrument is played closer in sync with the grid and the other is somewhat late.

The remaining laid-back recordings (clusters OM*4*, OM*5*, and OM*8*) are proximal to the purely on-beat clusters and subsumed by the on-beat archetype, (that is, no asynchrony to the grid and lack of inter-instrument asynchrony on average).

Pushed: The pushed performances are mainly found in five purely pushed clusters (OM*1*, OM*7*, OM*12*, OM*13*, and OM*16*), which contain 18 out of 20 pushed performances in all.

Pushed clusters OM*1* and OM*16* reveal a '*general earliness*' strategy, the archetype of which reflects a tendency to play all the instruments consistently early in relation to the grid (> 60%).

Pushed cluster OM*7* presents a '*general earliness + early kick flam*' strategy. Here too, all instruments are generally early in relation to the grid (> 60%), but additionally feature a frequent early kick flam (40–60 %). Pushed cluster OM*12* is characterised by an '*early snare flam*' strategy.

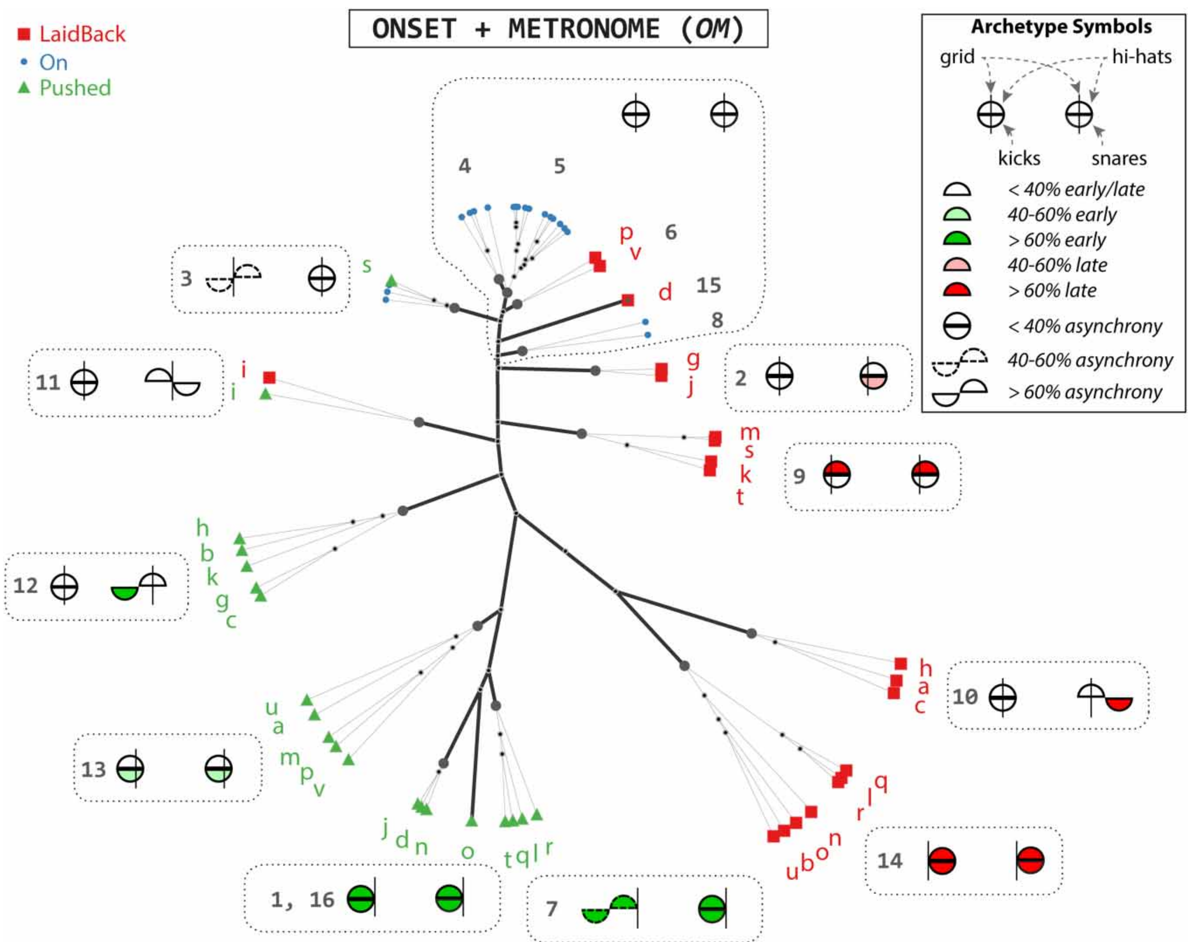

Figure 7. Phylogenetic tree of the onset timing clusters in the metronome condition ($_{OM}$). Each leaf (red/green/blue) corresponds to the onset profile of a single recording. The labels 1–16 correspond to the assigned clusters in the onset metronome (^{OM}) matrix (Figure A3). Next to each cluster, the corresponding onset archetype is shown. Key note: "early/late" = *early/late relative to the grid*, "asynchrony" = *inter-instrument asynchrony*.

Its performances are characterised by a tendency to play the snare and hi-hat asynchronously in a consistent fashion (> 60%), with the hi-hat synchronous (> 60%) relative to the grid, and the snare flammed early against it (> 60 %).

Pushed cluster $_{OM}$*13* reveals an '*ambiguously early compound sound*' strategy – a subtler form of earliness, whereby, at each metrical beat position, at least one instrument is on-beat relative to the grid but the other is played early (in this case, the snare and kick strokes, respectively).

On-beat: The majority of on-beat performances (18 out of 20) are found in clusters $_{OM}$*4* and $_{OM}$*5* and are characterised by all drum strokes being synchronous to the grid. The matrix (Figure A3) reveals that the main difference between them stems from the tendency of drummers in cluster $_{OM}$*4* to play the kick drum ahead of the hi-hat, though not in any consistent manner (< 40%).

3.1.2. Backing track (OB)

As was the case with the performances against the metronome, the classification of the onset profiles from the performances against the backing track ($_{OB}$) shows that almost all of the laid-back and pushed performances form separate homogenous clusters (see tree Figure 8 and matrix Figure A4). Once again, as expected, they are characterised by some degree of lateness or earliness relative to the grid, respectively, and this is again achieved using different rhythmic strategies.

Laid-back: 19 out of the 20 twenty instructed laid-back performances appear in six purely laid-back clusters with different forms of laid-back onset timing ($_{OB}$*1*, $_{OB}$*13*, $_{OB}$*14*, $_{OB}$*15*, $_{OB}$*9*, and $_{OB}$*10*).

Laid-back cluster $_{OB}$*10* reveals a hybrid '*general lateness + late kick flam*' strategy (akin to that of the sub-branch of cluster $_{OM}$*14*).

Laid-back cluster $_{OB}$*15* reveals a '*late snare flam*' strategy, similar to that of laid-back metronome cluster $_{OM}$10,

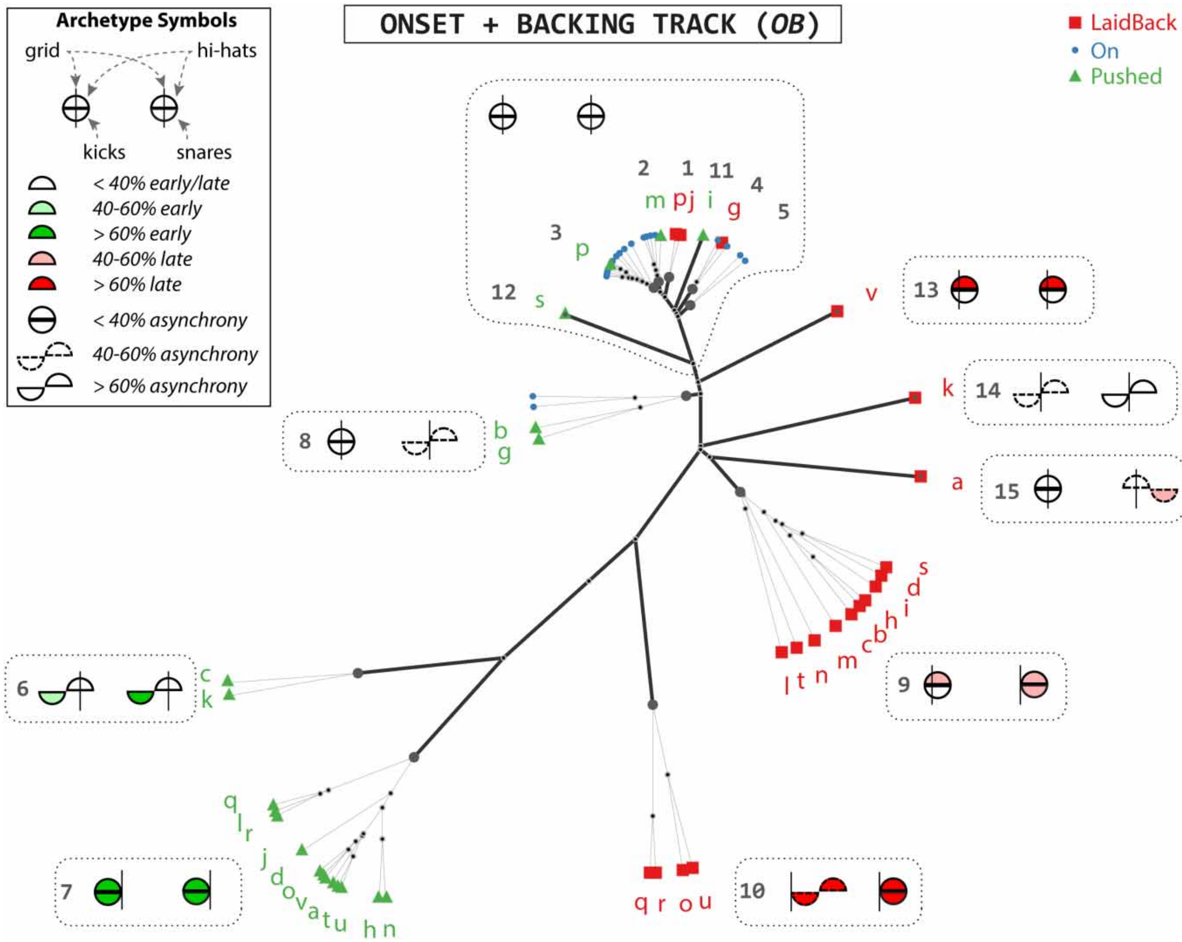

Figure 8. Phylogenetic tree of the onset timing clusters in the backing track condition ($_{\mathrm{OB}}$). Each leaf (red/green/blue) corresponds to the onset profile of a single recording. The numbers 1–15 correspond to the assigned cluster labels in the onset backing track ($_{\mathrm{OB}}$) matrix (Figure A4). Next to each cluster, the corresponding onset archetype is shown. Key note: "early/late" = *early/late relative to the grid*, "asynchrony" = *inter-instrument asynchrony*.

albeit in a weaker form, as the late snare flam is played less consistently (40–60%). Here, only one participant utilised this strategy. Cluster $_{\mathrm{OB}}$*14* is a variant of this strategy, with an early kick/snare and late hi-hat.

Laid-back clusters $_{\mathrm{OB}}$*9* and $_{\mathrm{OB}}$*13* are both characterised by an '*ambiguously late compound sound*' strategy, where both snare and kick are on-beat, but the hi-hats are played late relative to the grid. Whereas $_{\mathrm{OB}}$13 includes only one participant, laid-back cluster $_{\mathrm{OB}}$9 represents the largest group, with ten performances, and presents a sort of '*lopsided*' variant of this strategy, where in addition to a late kick/hi-hat compound sound (40–60%) on the downbeats, both the snares and the hi-hats are frequently played late relative to the grid (40–60%) on the upbeats, but are synchronous with one another.

Pushed: 14 out of 20 pushed performances appear in purely pushed clusters with archetypes characterised by some sort of generally early stroke onset timing ($_{\mathrm{OB}}$*6* and $_{\mathrm{OB}}$*7*).

Pushed cluster $_{\mathrm{OB}}$*7* was the most populated (12 out of 20 performances), and characterised by a '*general earliness*' strategy, where all instruments were consistently played early relative to the grid ($>60\%$). A closer examination of the tree reveals a sub-branch formed by participants '*q*', '*l*', and '*r*' resembling a '*general earliness + early kick flam*' variant strategy (just as in pushed cluster $_{\mathrm{OM}}$*7*; for details see the matrix in Figure A4).

Finally, pushed cluster $_{\mathrm{OB}}$*6* is characterised by a pure '*early flam*' strategy where hi-hats are on-beat with the grid, but both the kick and the snare are played early.

On-beat: Most of the on-beat performances (18 out of 20) appear in proximal clusters $_{\mathrm{OB}}$*1*, $_{\mathrm{OB}}$*2*, $_{\mathrm{OB}}$3, $_{\mathrm{OB}}$*4*, $_{\mathrm{OB}}$5, and $_{\mathrm{OB}}$*11*, and all are characterised by all of the drum strokes being synchronous to the grid. The matrix (Figure A4) reveals a slight tendency for drummers to play the kick drum ahead of the hi-hat on average, but not consistently ($<40\%$).

3.2. Intensity

3.2.1. Metronome (IM)

In contrast to the onset profiles, the classification of the intensity profiles in the metronome condition ($_{\mathrm{IM}}$) presents no clear separation between clusters of laid-back and pushed performances (see tree Figure 9 and matrix Figure A5). Instead, the majority of the performances (26 out of 40) displayed some form of consistent intensity differences between on-beat and off-beat timing in general (laid-back/pushed).

One pattern that emerges here involves off-beat performances (laidback/pushed) where the hi-hat is louder relative to the on-beat performances (10 out of 40). This takes one of three forms: greater hi-hat intensity alone ($_{\mathrm{IM}}$*4*); louder hi-hat combined with louder or weaker snare/kick ($_{\mathrm{IM}}$*7*, $_{\mathrm{IM}}$*9*, and $_{\mathrm{IM}}$*15*); or unchanged hi-hat intensity combined with a decrease in kick or snare intensity, essentially foregrounding the intensity of the hi-hat in relation to that of the other instruments ($_{\mathrm{IM}}$*11*). Conversely, only one cluster ($_{\mathrm{IM}}$*13*) featured an archetype where the hi-hat was played with lesser intensity (3 out of 40 performances). Another pattern involves off-beat performances where the *snare* is louder relative to the on-beat performances (13 out of 40), ($_{\mathrm{IM}}$*1*, $_{\mathrm{IM}}$*7*, $_{\mathrm{IM}}$*12*, and $_{\mathrm{IM}}$*13*). As for the kick, the opposite pattern is present: 12 out of 40 performances displayed a lesser kick intensity ($_{\mathrm{IM}}$*7*, $_{\mathrm{IM}}$*8*, $_{\mathrm{IM}}$*9*, and $_{\mathrm{IM}}$*11*) and only one higher ($_{\mathrm{IM}}$14)

Comparing the metronome onset and intensity profile trees, we see that, out of the eight performances that displayed no consistent onset lateness/earliness relative to the grid in either the laid-back or the pushed performances, five drummers did in fact display consistent intensity strategies for those very same performances (laid-back: '*d*', '*i*', '*j*'; pushed: '*s*', '*i*'). The laid-back performance of participant '*d*', for example, was categorised within an archetype in which all instruments were played on-beat relative to grid (cluster $_{\mathrm{OM}}$*15*); however, according to the corresponding onset matrix (see Figure A5),

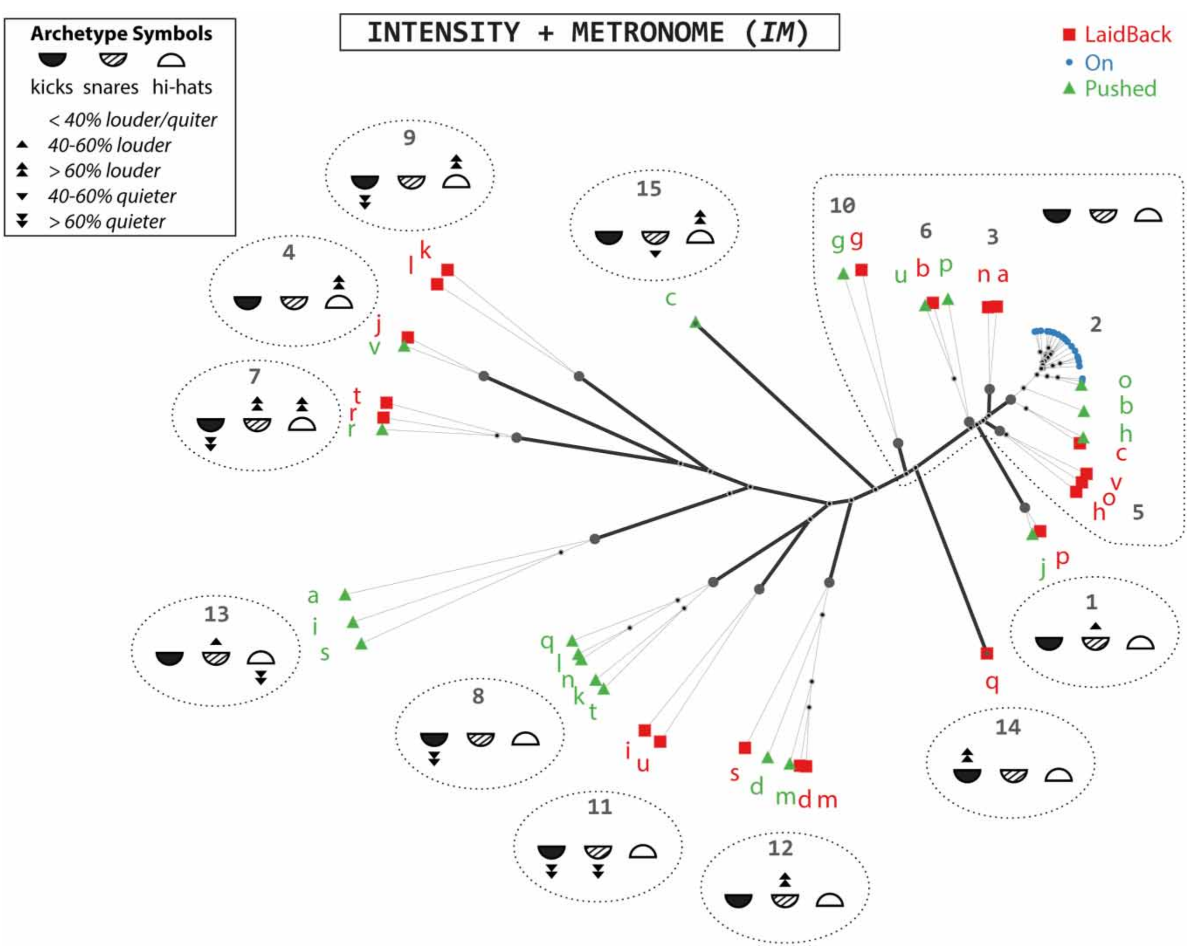

Figure 9. Phylogenetic tree of the intensity clusters in the metronome condition ($_{\mathrm{IM}}$). Each leaf (red/green/blue) corresponds to the onset profile of a single recording. The labels 1–15 correspond to the assigned clusters in the intensity metronome ($_{\mathrm{IM}}$) matrix (Figure A5). Next to each cluster, the corresponding onset archetype is shown. Key note: "early/late" = *early/late relative to the grid*, "asynchrony" = *inter-instrument asynchrony*.

it also showed a weak tendency for the snare to be played late.

Clusters $_{IM}$*10*, $_{IM}$6, $_{IM}$*3*, $_{IM}$*2*, and $_{IM}$*5* (14 out of 40 performances) are all subsumed by the '*no intensity change*' archetype, evoking a strategy characterised by a lack of any consistent drum intensity differences.

3.2.2. Backing track (IB)

Like the metronome condition, the classification of the intensity profiles for the backing-track ($_{IB}$) condition shows no clear separation between clusters of laid-back and pushed performances (see tree Figure 10 and matrix Figure A6). Instead, most of the performances (32 out of 40) cluster under archetypes with some form of consistent intensity differences between on-beat and laid-back/pushed.

Also, in the backing track condition there is a greater frequency of offbeat performances with louder hi-hats (12 out of 40: $_{IB}$5, $_{IB}$6, $_{IB}$9, and $_{IB}$*10*) than softer hi-hats (3 out of 40: $_{IB}$*17*). As for the use of snare intensity differences, the picture is mixed, with greater intensity in 5 out of 40 performances ($_{IB}$*8)* and lower in 3 out of 40 ($_{IB}$6). Regarding intensity differences in the kick, in contrast to the metronome condition, the backing-track condition saw more performances grouped under archetypes with a louder kick (10 out of 40: $_{IB}$*3*, $_{IB}$*8*, and $_{IB}$*10)* than a softer kick (7 out of 40: $_{IB}$*2* and $_{IB}$6). In the case of cluster $_{IB}$*2*, as kick intensity alone decreases, either the hi-hat or the snare may be heard as relatively louder.

When we compare the backing-track onset and intensity profile trees, we see that 8 out of the 9 performances that did not display any consistent onset-feature difference in either laid-back or pushed conditions, did in fact display consistent *intensity* strategies in their off-beat performances, relative to their respective on-beat performances (laid-back: '*g*', '*j*', and '*p*'; pushed: '*b*', '*g*', '*i*', '*m*', '*s*').

Clusters $_{IB}$*1* and $_{IB}$*4* fall under a 'no intensity change' archetype and are characterised by a general lack of consistent drum intensity differences between performances

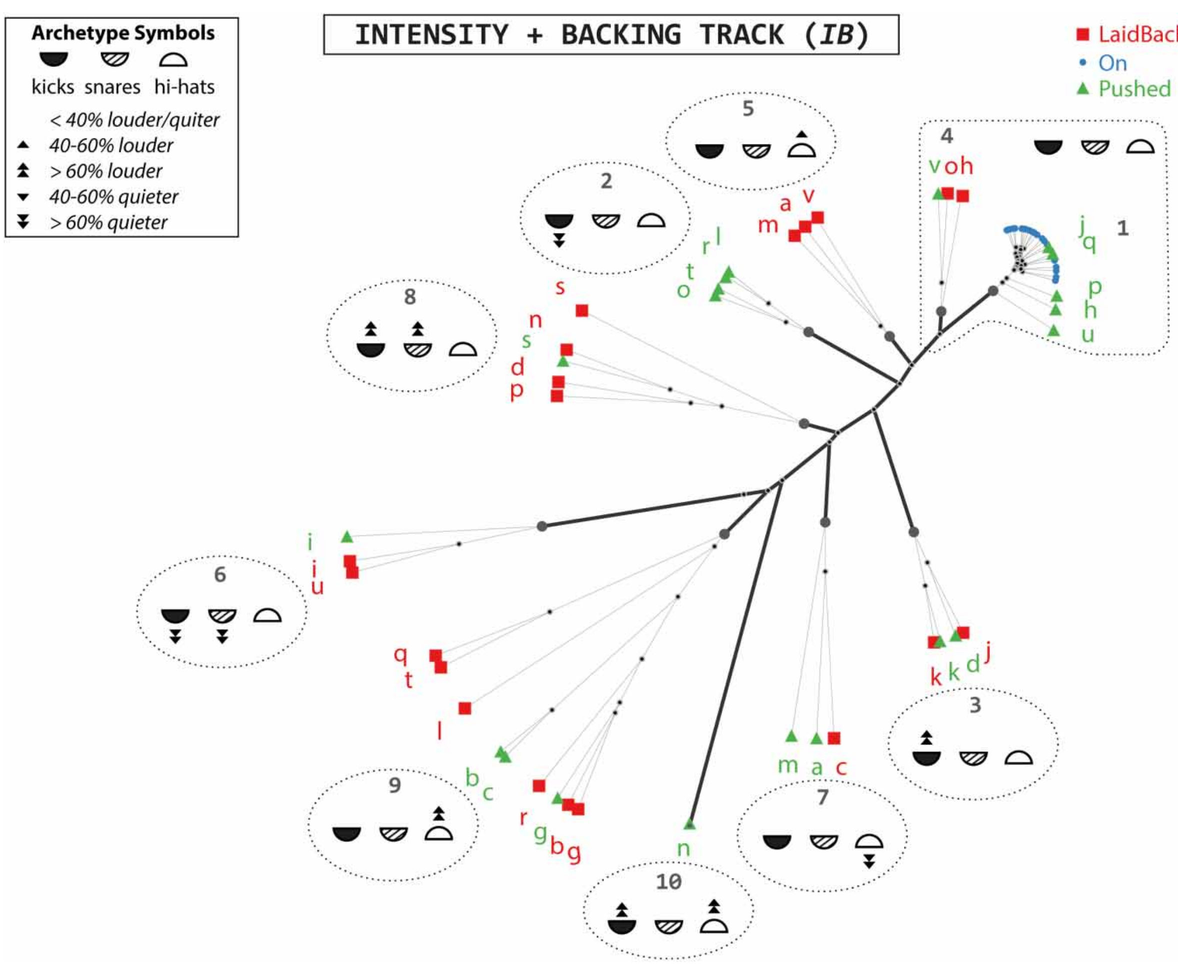

Figure 10. Phylogenetic tree of the intensity clusters in the backing-track condition ($_{IB}$). Each leaf (red/green/blue) corresponds to the onset profile of a single recording. The numbers 1–10 correspond to the assigned cluster labels in the intensity backing-track ($_{IB}$) matrix (Figure A6). Next to each cluster, the corresponding onset archetype is shown. Key note: "early/late" = *early/late relative to the grid*, "asynchrony" = *inter-instrument asynchrony*.

(8 out of 40 in all). All participants here, however, apply strong onset strategies in their laid-back and/or pushed performances (see Figure 8).

4. Discussion

Previous studies of instructed microtiming experiments with drummers (Câmara et al., 2020b; Danielsen et al., 2015; Kilchenmann & Senn, 2011) have shown that when drummers are instructed to play laid-back and pushed performances, the average stroke onsets of drum-kit instruments are significantly later and earlier, respectively, relative to on-beat performances. As expected, then, when distinguishing their laid-back and pushed performances from their respective on-beat performances, we found that drummers tended to play at least one drum instrument late or early relative to the grid. However, unlike previous studies that mainly focus on group averages, the analyses of our individual participant onset and intensity profiles and the phylogenetic tree clustering methodology further show that drummers adopt a range of distinct strategies to achieve laid-back and pushed playing. These strategies differ in terms of onset asynchrony relative to the grid and between simultaneous instruments, as well as in dynamic accentuation of certain instruments. In the following discussion, we focus on the main trends of onset and intensity strategies chosen by drummers between the different timing style and reference track conditions.

4.1. Onset strategies

A first thing to note is that our results show that expressing intentionally 'laid-back' and 'pushed' timing feels in drum-kit performance does not necessarily entail a systematic delaying or anticipating of all drum instruments' onset timing against the instruments of an ensemble or a metronomic timing reference, respectively. Moving all instruments early or late is simply one of many possibilities, considering that the timing of at least three different instruments can be manipulated independently in performance of a basic drum-kit (kick, snare, hi-hat). Individual player preferences and genre/style context probably play a role as to what strategies drummers choose to convey a given timing feel, amongst several other factors (Câmara et al., 2020b; Danielsen et al., 2015; Kilchenmann & Senn, 2011). Accordingly, we found a variety of onset strategies in the performance of just a simple back-beat pattern.

Overall, however there appears to be roughly three main strategies that drummers tend to adopt: (1) strong '*general earliness/lateness*' strategies, where most, if not all, instruments are consistently played earlier/later in time relative to the grid; (2) subtle '*early/late flam*' strategies, where most instruments are played synchronously with the grid but at least one instrument is played early or late; and (3) even subtler '*ambiguously early/late compound sound*' strategies, where, within a compound sound, one instrument is played synchronous with the grid while the other is played early/late, but the onset distance between the two instruments is not large enough to be considered a true inter-instrument asynchrony (or flam). There were also hybrid variants of the main strategies, that is, '*general earliness/lateness + kick flam*' approach and a '*lop-sided*' ('*general lateness + ambiguously late compound sound*') strategy, where the kick/hi-hat combination fell ambiguously late in relation to the grid, but the snare/hi-hat combination fell clearly late (and in sync with each other). Importantly, onset strategies were used by almost all participants and only a few participants did not consistently distinguish either their laid-back or pushed performances from their respective on-beat performances (and rarely both) in terms of late/early timing relative to the grid. However, those performances often did present either a marginal degree of corresponding earliness/lateness (only less than 40 per cent of the time) or less consistent inter-instrument asynchronies (see matrix Figures A3 and A4). An overview of the timing strategies chosen by each participant as related to these categories can be found in Table A1 in Appendix A.

Another notable result is that drummers tend to use different strategies for laidback and pushed. Regarding timing style, less than half of the participants (10 with the metronome, and 5 with the backing track) adopted the same type of approach for both laid-back *and* pushed conditions – that is, used strategies that were of the same category type (e.g. '*general lateness*' vs. '*general earliness*'). The remaining majority (10 with the metronome, and 15 with the backing track) differentiated their approaches for the laid-back and pushed conditions (e.g. '*general lateness*' vs. '*early snare flam*'). As for timing reference, here too, less than half of the drummers utilised the same type of strategy when playing with the metronome and the backing track (4 in the laid-back, and 11 in the pushed), while the majority adopted different approaches (16 in the laid-back, and 9 in the pushed). This breakdown is in line with previous research, which shows that drummers tend to develop individualised strategies to achieve the same desired rhythmic effect (Dahl, 2004; Danielsen et al., 2015; Waadeland, 2006), and further suggests that timing reference also affects such strategies.

Regarding '*general earliness/lateness*' strategies, we found that they were equally popular for the laidback and pushed timing styles in the metronome condition. In the backing track condition, these strategies were also popular in the pushed condition but much less so in the laid-back performances (4 out of 20), giving way to 'lop-sided' hybrid strategies with synchronised downbeats but late back-beats (10 out of 20). This finding agrees with claims from several empirical groove performance studies that drummers favour the use of delayed snare strokes on beats 2 and 4 in particular (a 'back-beat delay') when supplying a laid-back feel to an ensemble performance (Butterfield, 2006; Frane, 2017; Iyer, 2002).

Generally, more participants chose the subtler approaches of flam and compound sound strategies for the laid-back condition. The opposite pattern characterises the pushed performances, so that participants opted more frequently for stronger '*general earliness*' approaches (with or without an extra flam; 20 out of 40 in total). Câmara et al. (2020b) previously found that, on average, drummers applied subtler and less consistent absolute magnitudes of asynchrony to the grid in laid-back compared to pushed performances. The explanation for this may be aesthetic in nature – drummers may consider laid-back timing approaches to be aesthetically amenable to more sporadic and subtler degrees of lateness, whereas they may consider more consistent and more pronounced earliness to be acceptable in pushed performances. On the other hand, in a pushed timing feel, the threshold for early strokes sounding rushed rather than pushed is arguably larger, allowing for more consistent and greater earliness magnitudes within a stable, driving momentum. To our knowledge, no one has yet investigated the differences in perceived onset asynchrony thresholds of off-beat late vs. early asynchronous events in a rhythmic context. An alternative explanation for this difference is that the pushed condition simply presents a greater technical challenge than the laid-back condition and thus results in more consistently and/or exaggeratedly early onset strokes.

As for pure flam strategies, we found that they were used less frequently to signal both laid-back and pushed performances in the backing-track condition (3 out of 40) as opposed to in the metronome condition (8 out 40). This may be related to the relative salience of flam effects generated by inter-instrument asynchronies in different reference contexts. In the metronome condition, where the percussive woodblock sounds have fast attacks and short durations, the flams created by the drum-kit instruments may stand out clearly in the total sound output, making them useful devices for drummers to communicate slight degrees of 'off-beatness'. In more ecological contexts such as the backing-track condition, however, the presence of relatively longer and wider bass and guitar sounds might mask drum-kit flams to a greater extent, potentially subsuming them within extended compound sounds, thus rendering such early/late flam strategies less effective, or even redundant, aesthetic devices. The relative salience of percussive drum flams against sounds and rhythmic layers of different types of instruments has not been investigated and is a topic for future research. Notably though, in both reference conditions, it appears that the hi-hat is predominantly the instrument closer to or on the grid in flam strategies. This may be related to the assumed role of the hi-hat as the 'timekeeper' of the drum kit (Câmara et al., 2020b). Therefore, when drummers opt for a subtler early/late flam approach, they may be using the hi-hat to maintain a relatively on-beat foundational rhythmic layer, and the snare or kick to signal an element of intended earliness/lateness to the performance.

4.2. Intensity strategies

The intensity profiles for both the metronome and the backing-track reference conditions show that most of the drummers utilised additional consistent intensity profiles to express timing feel. Unlike their behaviour in the corresponding onset profiles, however, the drummers did not necessarily apply one direction of change (greater or lesser intensity) to individual instruments in order to distinguish laid-back or pushed from on-beat timing feels. Theoretical studies have suggested that dynamic accentuation can be used instead of, or in combination with, onset deviations to perceptually draw attention to microrhythmic events in particular instruments or instrument relationships (Butterfield, 2011; Iyer, 2002). Therefore, the prevalence of mixed laid-back and pushed clusters in the analyses of both metronome and backing track conditions suggests that the drummers may use dynamic intensity accents to either highlight or soften the effect of irregular or slightly off-the-beat rhythmic elements in both laid-back and pushed performances.

Overall, the most common intensity strategies utilised to distinguish laid-back and pushed from on-beat performances were those that applied a degree of greater hi-hat or snare intensity. This is even more the case if we include intensity strategies in which kick loudness is decreased relative to the on-beat performance, but hi-hat and snare intensities remain the same (e.g. clusters $_{\mathrm{IM}}8$ and $_{\mathrm{IB}}2$). These results are somewhat expected, as findings from our previous investigation (Câmara et al., 2020b) showed that the group average intensity across all participants was greater for hi-hat and snare in both the laid-back and the pushed conditions compared to the on-beat condition.[2] Whereas the former

[2] This is based on the descriptive statistics of the average group ($N = 20$) values of the metronome and instrumental (backing-track) timing reference conditions of 'pattern 1' ('simple back-beat') separately, as displayed

study indicated that the general trend across all drummers was to play the hi-hat and snare louder to distinguish both off-beat timing style conditions from the on-beat condition in performance, this study further reveals that a diversity of intensity strategies is in fact present within the group.[3] The prevalence of louder hi-hat intensity strategies in both laid-back and pushed conditions may also be related to the hi-hat's role as a timekeeper.

Although intensity is undoubtedly a vital component of rhythmic expression more generally, its role as a mediator for communicating intended timing feel in drum performances more specifically remains less clear as that of onset manipulation. While Goebl and Parncutt (2002) and Tekman (2002) found that, in simple rhythmic contexts, late and loud sound combinations tend be perceived as more asynchronous than early and loud ones due to forward masking effects, we cannot necessarily expect this to be the case in complex musical contexts. This is because the asynchronous events are heard against more than one rhythmic layer (multiple instruments plus timing reference) at any given time. Therefore, even in the case of laid-back and pushed performances that expressed consistent strong or subtle early/late onsets, an increase in any given instrument's intensity may at once increase its own perceptual salience in the sonic output of the performance and simultaneously enhance or diminish the salience of the other instruments' earliness/lateness. It is interesting, however, that in the instances of pushed and laid-back performances where drummers did *not* utilise any consistent onset strategy, most of them did in fact consistently manipulate intensity features to distinguish those conditions from the respective on-beat condition, and some of them also appear to have increased the intensity of onset features with borderline early/late tendencies as a means of highlighting their off-beat character. As such, the role of intensity as a communicator of timing feel in drum kit playing is perhaps more indirect, and further investigation is warranted before drawing any firm conclusions.

Ultimately, it is to be noted that in all these performance strategies, the extent to which the produced timing asynchronies or dynamic accentuations can be perceived is likely to depend on a range of factors, such as magnitude, tempo, and musical expertise. (We further invite the reader to examine selected audio examples of various onset and intensity strategies in Table B1 in Appendix B.) While some heuristic thresholds exist for such aspects in monophonic and/or simple rhythmic listening contexts (see Frane & Shams, 2017; Friberg & Sundberg, 1995), none appear to exist for complex, polyphonic, and musical contexts such as those investigated in this study. Therefore, it is generally difficult to draw firm conclusions as to the perceptual effects that these different strategies may engender, and further research into thresholds for perceiving onset and intensity nuances in more complex auditory contexts is needed.

5. Conclusion

Our analyses show that drummers utilise different stroke-onset and intensity strategies in order to express a simple 'back-beat' pattern with different intended timing styles (laid-back, on-beat, pushed). We identified at least three main onset strategies in our data set: strong 'general earliness/lateness' strategies, subtler 'early/late flam' strategies, and even subtler 'ambiguously early/late compound sound' strategies.. Most of the participants utilised additional consistent intensity strategies as well, the most common being those that applied a degree of greater hi-hat or snare intensity in the laidback and pushed conditions. Intensity, however, was not necessarily applied uniformly in order to exclusively distinguish either laid-back or pushed from on-beat timing feels, but rather as a potential means of enhancing or diminishing the effect of slightly asynchronous rhythmic elements more generally.

Our analyses also show that hierarchical clustering methods combined with phylogenetic tree visualisations and archetype classification offer an effective way to navigate and map a large number of recordings/performances based on a set of informed features such as timing of stroke onset and intensity. Though we offer only a partial investigation, future inclusion of additional onset and intensity relations, as well as relations among other performance features such as duration and timbre, would be relatively simple to implement and shed further light on the myriad ways in which musicians may express timing feels in performance.

Overall, while our findings suggest that manipulating stroke onset remains the primary vehicle for expressing timing feel in drum-kit performance, intensity may serve to further modulate the salience of earliness/lateness relative to a timing reference as well as more subtle inter-instrument onset asynchronies. Further research

in Figure 8 of Câmara et al. (2020b) and not on the average value of all timing reference and pattern conditions that included an additional rhythmic pattern ('pattern 2,' 'complex').

[3] It should be noted that, due to the more conservative thresholds chosen for classification of a stroke as louder/softer (or early/late, for that matter), fewer performances would be classified as such in the archetype system. Therefore, it may still be the case that an even greater number of individual drummers did in fact play with higher snare/hi-hat intensity in the laid-back and pushed conditions, but not at absolute average values lower than the respective SD thresholds of consistently more than 40 percent of the time during performances.

is warranted concerning the role of intensity in communicating timing feel, including experiments wherein drummers (and other instrumentalists) are instructed to play laid-back or pushed timing by manipulating *only* the intensity of their strokes rather than the onsets. More systematic perceptual listening experiments should also be conducted in rhythmically multilayered, musical contexts.

The study provides new insights into the frequency and range of onset and intensity archetypes used to distinguish laid-back and pushed performances from on-beat ones, Importantly, it also provides an overview of the more popular/typical strategies used to express intended microrhythmic feels in simple back-beat contexts. That said, despite our attempt to design an experiment with legitimate ecological validity that resembled a real musical performance (without sacrificing too much control over the variables) – and despite the fact that several participants did remark in their post-interviews that the experiment felt akin to recording in a solo-studio situation – it remains the case that these drummers were playing in a somewhat artificial context. Therefore, one should be cautious to assume that drummers would utilise the exact same onset-timing and intensity strategies in real-world musical situations. Expert musicians are highly adaptable, and there are so many genre and instrumental ensemble contexts to which this simple back-beat pattern is applicable.

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Appendices

Appendix A

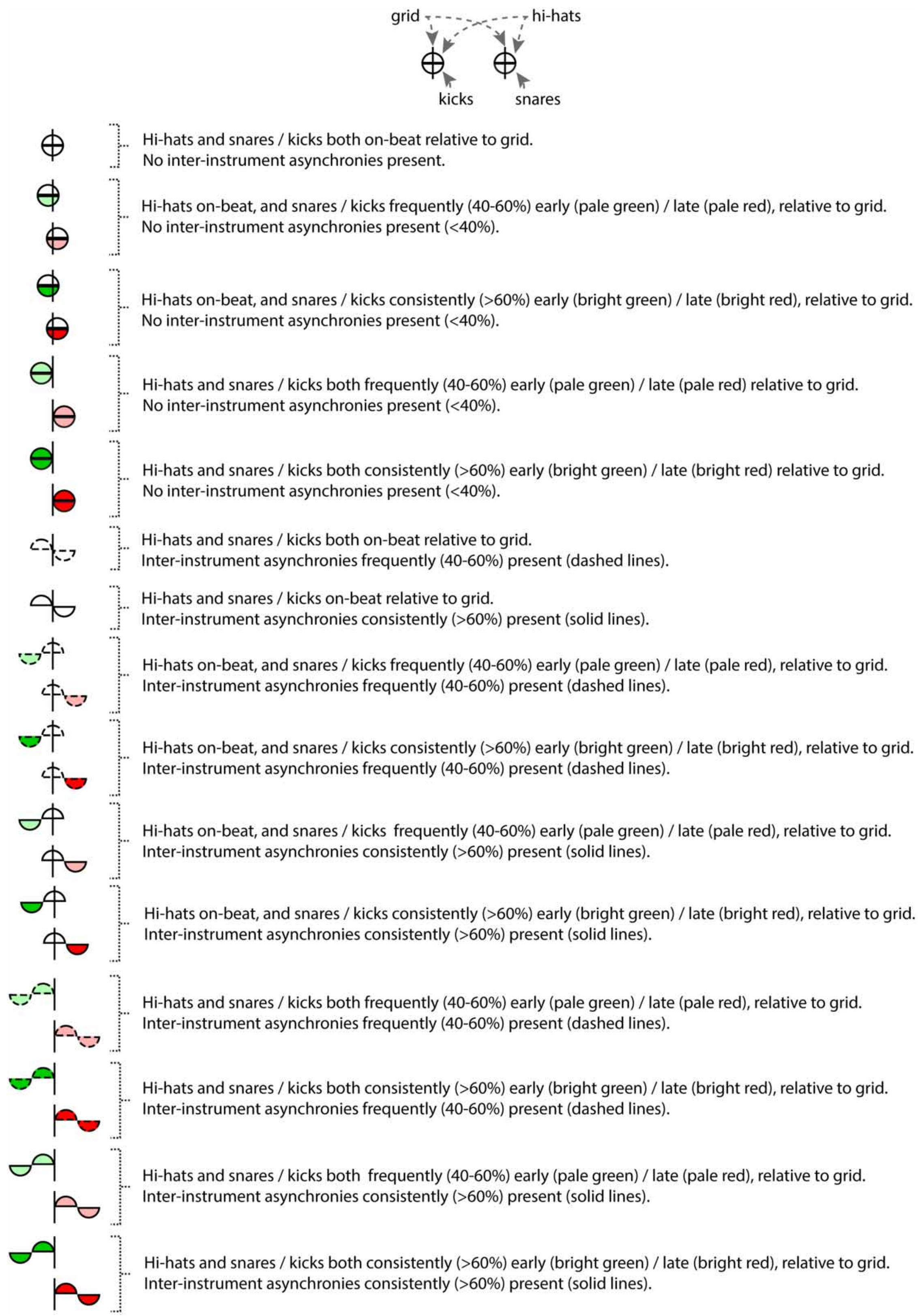

Figure A1. Detailed onset archetype symbol explanation.

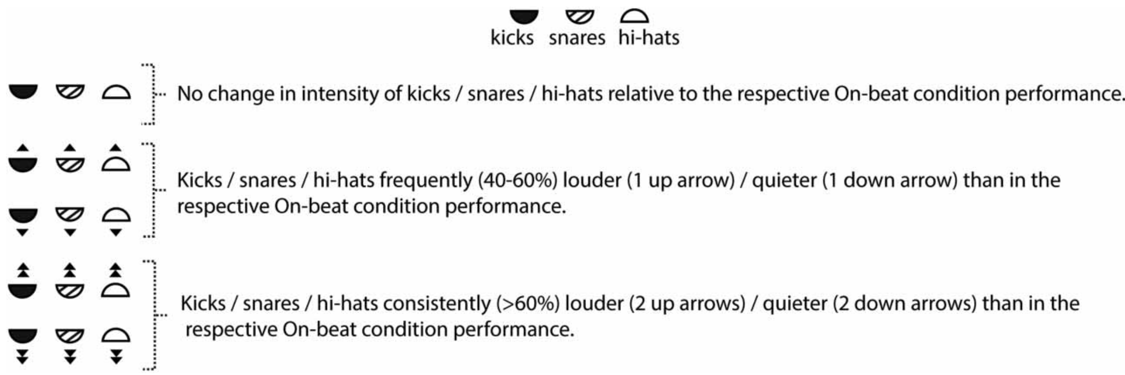

Figure A2. Detailed intensity archetype symbol explanation.

Similarity matrix figures

In all the similarity matrices below (Figures A3–A6), onset or intensity features are laid along the horizontal axis. On the vertical axis, the first column of numbers indicates the assigned cluster labels; the second column of letters, the participant ID; and the third column of letters, the instructed timing style condition (on-beat = 'O' [blue]; laid-back = 'L' [red]; pushed = 'P' [green]). Horizontal dashed lines represent the cluster boundaries. The recordings (rows) are ordered according to the results of the hierarchical clustering, so that clustered recordings are adjacent in the matrix. The features (columns) are organised according to whether they correspond to 'late' or 'early' onsets / 'louder' or 'quieter' intensities relative to the hi-hat or metrical grid and based on their metrical position.

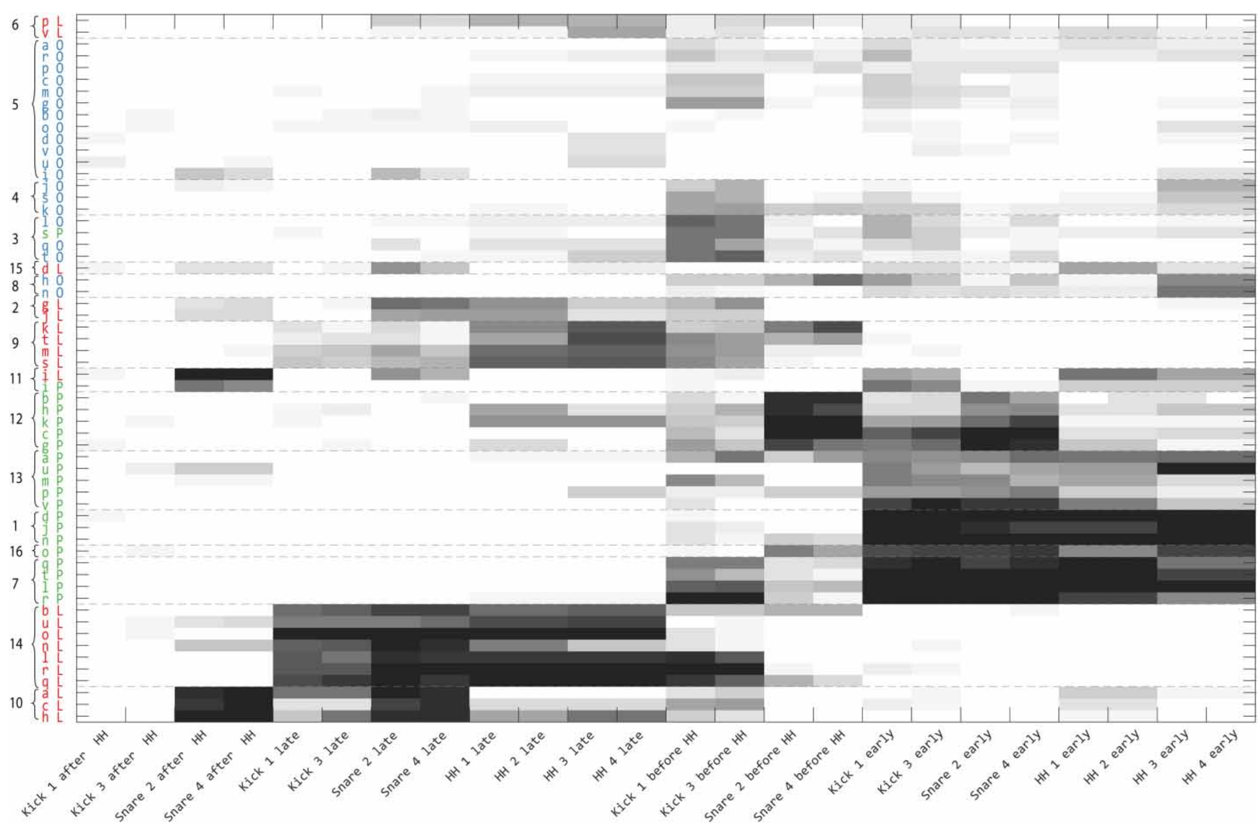

Figure A3. Onset profiles for all recordings in the metronome condition ($_{OM}$) shown as a greyscale matrix representing the probability or frequency with which a feature is encountered in a recording (white = 0%, black = 100%). Note: HH = hi-hat.

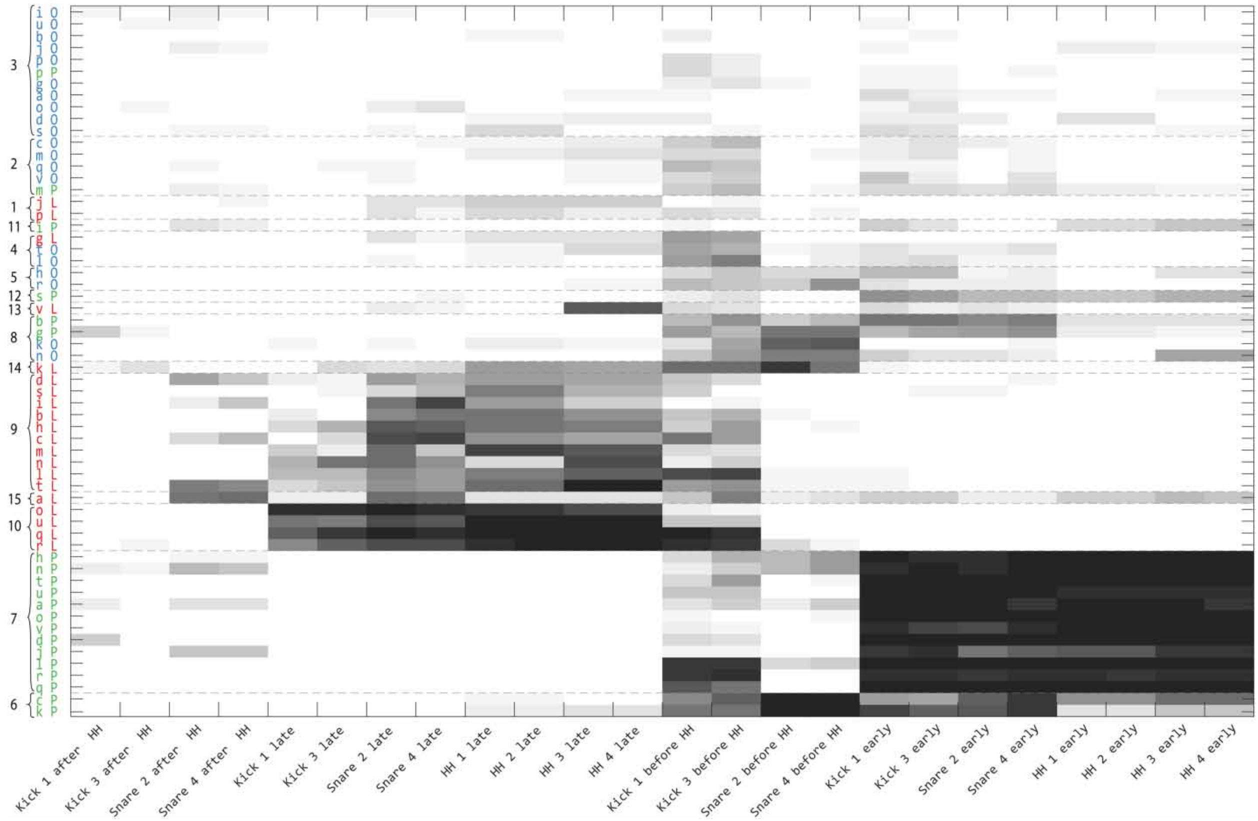

Figure A4. Onset profiles for all recordings in the backing track condition ($_{OB}$), shown as a greyscale matrix representing the probability or frequency with which a feature is encountered in a recording (white = 0%, black = 100%). Note: HH = hi-hat.

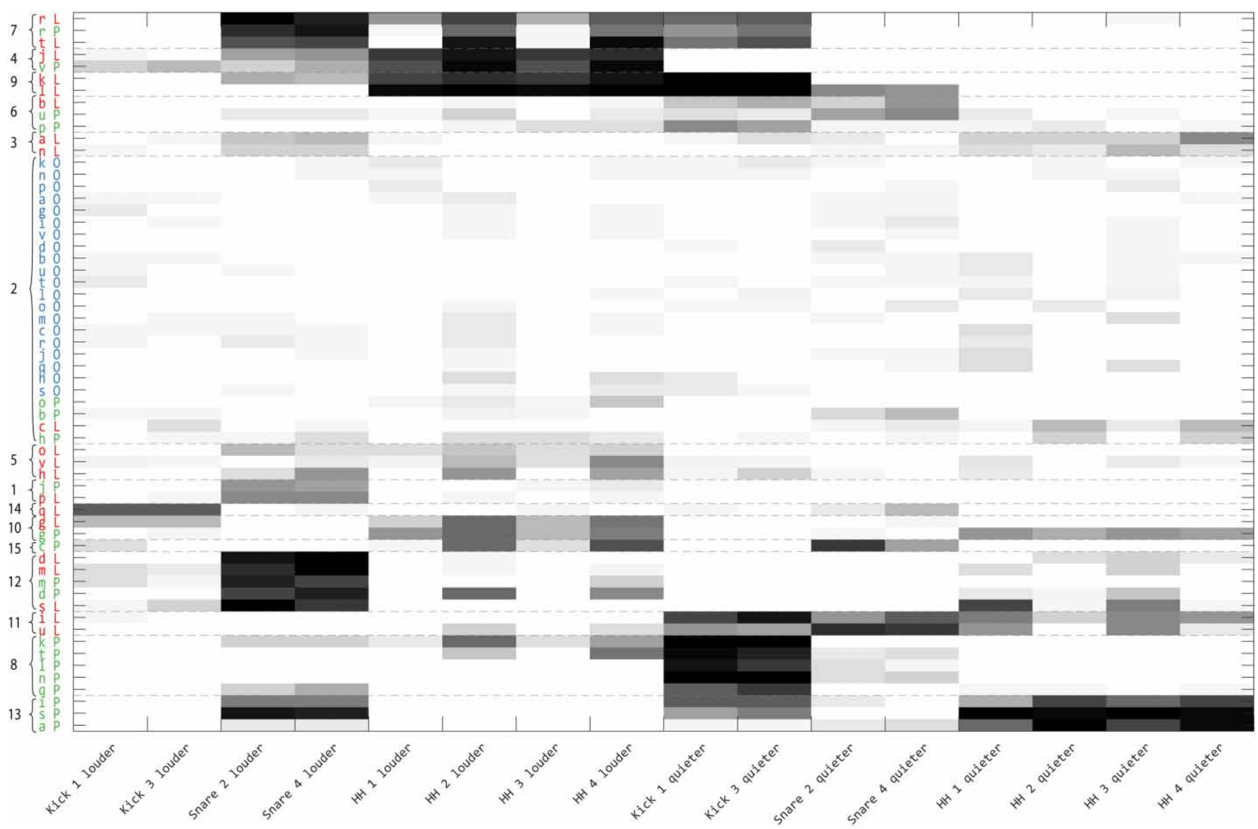

Figure A5. Intensity profiles for all recordings in the metronome condition ($_{IM}$), shown as a greyscale matrix representing the probability or frequency with which a feature is encountered in a recording (white = 0%, black = 100%). Note: HH = hi-hat.

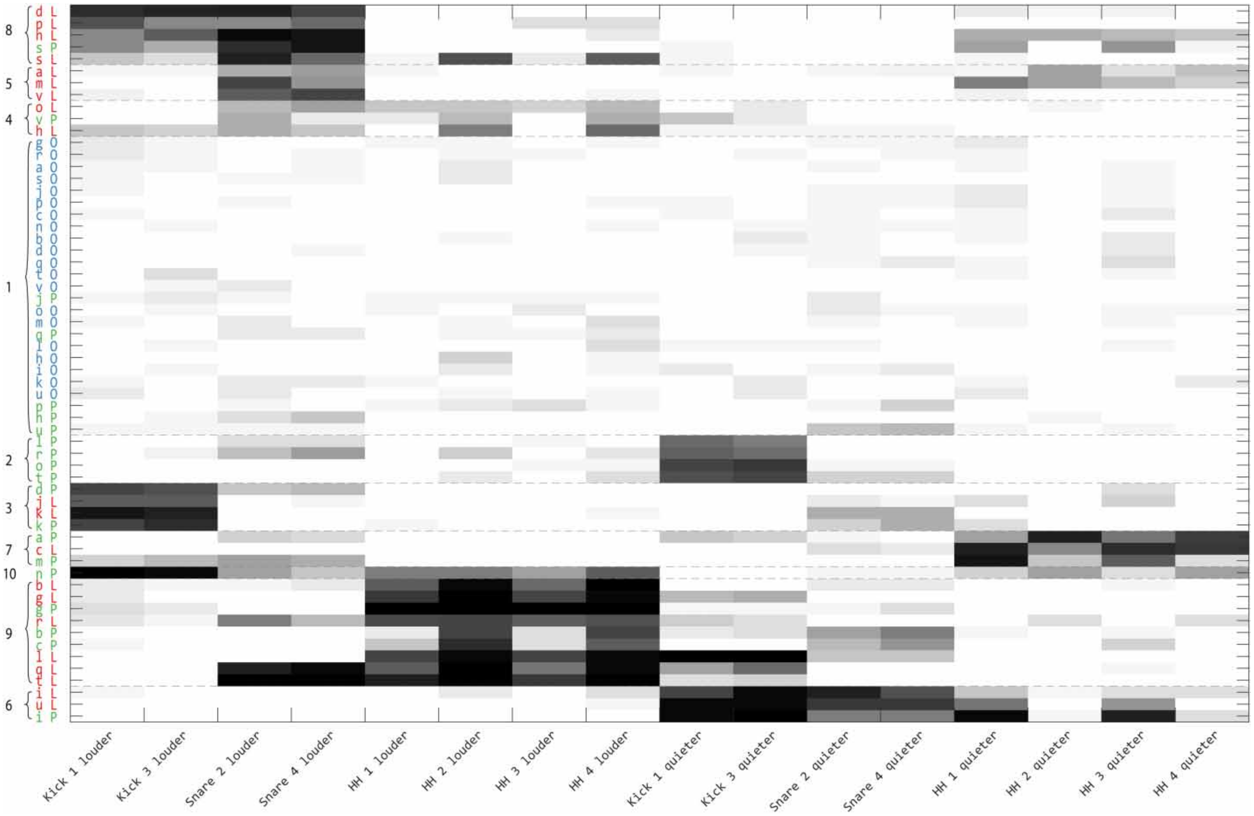

Figure A6. Intensity profiles for all recordings in the backing-track condition ($_{IB}$), shown as a greyscale matrix representing the probability or frequency with which a feature is encountered in a recording (white = 0%, black = 100%). Note: HH = hi-hat.

Table A1. Overview of onset strategy categories for all Laid-back and Pushed performances in the Metronome and Backing Track reference conditions.

	Metronome			
	Laid-back		Pushed	
Pt.	Onset category	Cluster	Onset category	Cluster
a	Late Flam	OM *10*	Compound Sound	OM *13*
b	General Lateness	OM *14*	Early Flam	OM *12*
c	Late Flam	OM *10*	Early Flam	OM *12*
d	General On-beat	OM *15*	General Earliness	OM *1*
g	Compound Sound	OM *2*	Early Flam	OM *12*
h	Late Flam	OM *10*	Early Flam	OM *12*
i	On-beat Flam	OM *11*	On-beat Flam	OM *11*
j	Compound Sound	OM *2*	General Earliness	OM *1*
k	Compound Sound	OM *9*	Early Flam	OM *12*
l	General Lateness + Flam*	OM *14*	General Earliness + Flam	OM *7*
m	Compound Sound	OM *9*	Compound Sound	OM *13*
n	General Lateness	OM *14*	General Earliness	OM *1*
o	General Lateness	OM *14*	General Earliness	OM *16*
p	General On-beat	OM *6*	Compound Sound	OM *13*
q	General Lateness + Flam*	OM *14*	General Earliness + Flam	OM *7*
r	General Lateness + Flam*	OM *14*	General Earliness + Flam	OM *7*
s	Compound Sound	OM *9*	On-beat Flam	OM *3*
t	Compound Sound	OM *9*	General Earliness + Flam	OM *7*
u	General Lateness	OM *14*	Compound Sound	OM *13*
v	General On-beat	OM *6*	Compound Sound	OM *13*

	Backing Track			
	Laid-back		Pushed	
Pt.	Onset Category	Cluster	Onset Category	Cluster
a	Late Flam	OB *15*	General Earliness	OB *7*
b	General Lateness + Compound Sound	OB *9*	On-beat Flam	OB *8*
c	General Lateness + Compound Sound	OB *9*	Early Flam	OB *6*
d	General Lateness + Compound Sound	OB *9*	General Earliness	OB *7*
g	General On-beat	OB *4*	On-beat Flam	OB *8*
h	General Lateness + Compound Sound	OB *9*	General Earliness	OB *7*
i	General Lateness + Compound Sound	OB *9*	General On-beat	OB *11*
j	General On-beat	OB *1*	General Earliness	OB *7*
k	On-beat Flam	OB *14*	Early Flam	OB *6*
l	General Lateness + Compound Sound	OB *9*	General Earliness + Flam*	OB *7*
m	General Lateness + Compound Sound	OB *9*	General On-beat	OB *2*
n	General Lateness + Compound Sound	OB *9*	General Earliness	OB *7*
o	General Lateness + Flam	OB *10*	General Earliness	OB *7*
p	General On-beat	OB *1*	General On-beat	OB *3*
q	General Lateness + Flam	OB *10*	General Earliness + Flam*	OB *7*
r	General Lateness + Flam	OB *10*	General Earliness + Flam*	OB *7*
s	General Lateness + Compound Sound	OB *9*	General On-beat	OB *12*
t	General Lateness + Compound Sound	OB *9*	General Earliness	OB *7*
u	General Lateness + Flam	OB *10*	General Earliness	OB *7*
v	Compound Sound	OB *13*	General Earliness	OB *7*

*Categorisation based on sub-branch of cluster (see Results sections [3.1.1] and [3.1.2])
Note: Pt. = Participant.

Appendix B

Below in Table B1, we provide audio examples of several drummers' onset and intensity strategies, as well as our own subjective interpretations of their perceptual effects. Examples were chosen from performances that exhibited the strongest features (greatest frequency %) of a given cluster archetype, based on the results of the matrices (see Figures A3–A6). All audio examples can be found via the Open Science Framework: https://osf.io/6uwf7.

Table B1. Audio examples and subjective interpretations of various onset and intensity strategies.

Audio examples	P.	Cluster	Onset strategy	Authors' comments
1a (On, solo) **1b** (On, w/ Metronome) **1c** (Laid-back, solo) **1d** (Laid-back, w/ Metronome)	*o*	$_{\mathrm{OM}}14$	General lateness	When heard solo (1a and 1c), the differences between laid-back and on-beat performances are not apparent, since in the former, all instruments are delayed relative to the grid and there is no external reference to judge their timing against. However, when heard in combination with the metronome stimuli, the lateness of all drumbeats relative to the metronome sounds becomes quite pronounced (1b and 1d).
2a (On, solo) **2b** (On, w/ Metronome) **2c** (Laid-back, solo) **2d** (Laid-back, w/ Metronome)	*l*	$_{\mathrm{OM}}14$	General lateness + early kick flam	The matrix (Figure A3) reveals a strong tendency to play a kick flam in the laid-back performances (2c and 2d). When we hear them against the on-beat performance–both solo (2a and 2c) and with metronome (2b and 2d)–the kick flams impart a slight anticipatory feel to the downbeats of the groove (though the effect is subtle), lending it a driving and insistent character in relation to the other sounds.
3a (On, solo) **3b** (On, w/ Metronome) **3c** (Laid-back, solo) **3d** (Laid-back, w/ Metronome)	*a*	$_{\mathrm{OM}}10$	Late snare flam	The late snare flams against the hi-hats in the laid-back performance can be readily heard compared to the 'tight' and synchronous on-beat performance, both in a solo context (3a and 3c) and against the metronome (3b and 3d).
4a (On, solo) **4b** (On, w/ Metronome) **4c** (Laid-back, solo) **4d** (Laid-back, w/ Metronome)	*s*	$_{\mathrm{OM}}9$	Ambiguously late compound sound	When heard solo (4a and 4c), the on-beat performance sounds 'tighter' or 'snappier' compared to the laid-back performance. In the latter the compound sound appears slightly stretched out in a late direction. This 'looseness' of events around the beats is also somewhat evident against the metronome: in the laid-back condition, the snare and kick sound are tightly synchronous with the woodblock, whereas the hi-hats trail slightly behind both, stretching the resultant denser compound sound of hi-hat, woodblock, and snare or kick, respectively (4b and 4d).
5a (On, solo) **5b** (On, w/ Metronome) **5c** (Pushed, solo) **5d** (Pushed, w/ Metronome)	*n*	$_{\mathrm{OM}}1$	General earliness	In the pushed performance, as all the instruments are shifted in the same early direction relative to the grid, the timing differences between on-beat and pushed conditions are not apparent when heard solo (audio examples 5a and 5c). However, against the metronome, a general pushing of all drums on the downbeats becomes more evident (audio examples 5b and 5d).
6a (On, solo) **6b** (On, w/ Metronome) **6c** (Pushed, solo) **6d** (Pushed, w/ Metronome)	*r*	$_{\mathrm{OM}}7$	General earliness + early kick flam	The early kick flams on the downbeats can be heard more clearly in solo comparisons of the pushed and on-beat performances (6a and 6c). Against the metronome (6b and 6d), the early kick flam seems to stretch out the downbeats somewhat, imparting a looser feel to the performance.
7a (On, solo) **7b** (On, w/ Metronome) **7c** (Pushed, solo) **7d** (Pushed, w/ Metronome)	*g*	$_{\mathrm{OM}}12$	Early snare flam	The early snare flams against the synchronised hi-hats can be heard rather clearly when comparing the laid-back with the on-beat performances, both solo (7a and 7c) and against the metronome (7b and 7d).
8a (On, solo) **8b** (On, w/ Metronome) **8c** (Pushed, solo) **8d** (Pushed, w/ Metronome)	*v*	$_{\mathrm{OM}}13$	Ambiguously early compound sound	In the on-beat performances (8a and 8c), the drums sound tightly synchronised with each other compared to the corresponding laid-back performances (8b and 8d), where the snare and kick seem to gently push against the downbeats, trailed ever so slightly by the hi-hats.

(*continued*).

Table B1. Continued.

Audio examples	P.	Cluster	Onset strategy	Authors' comments
9a (On, solo) **9b** (On, w/ Backing Track) **9c** (Laid-back, solo) **9d** (Laid-back, w/ Backing Track)	*r*	$_{OB}$*10*	General lateness + late kick flam	The kick flams against the hi-hats on the downbeats are rather clear when comparing the solo laid-back and on-beat performances (9a and 9c). Coupled with the late snare/hi-hat combination on the upbeats, it introduces a slight decelerating/accelerating feel to the performance. Against the backing track (9b and 9d), the double-stroke effect of the flam between kick and bass becomes starker, as does the resultant flam between the snare and guitar.
10a (On, solo) **10b** (On, w/ Backing Track) **10c** (Laid-back, solo) **10d** (Laid-back, w/ Backing Track)	*h*	$_{OB}$9	General lateness + ambiguously late compound sound ('lopsided')	A sort of 'lopsided' effect can be felt in the laid-back performance, especially in the solo context (10a and 10c). If the synchronised kick/hi-hat compound sounds on the downbeats are heard as primary in establishing the pulse, every snare/hi-hat stroke arrives just a little later than expected. The effect could also be described as a 'slowing-down/speeding-up' effect. When we hear these performances in relation to the backing track (10b and 10d) though, the effect is somewhat mitigated, as the lateness of both kick and snare seem to blend with the on-beat bass and guitar strokes.
11a (On, solo) **11b** (On, w/ Backing Track) **11c** (Laid-back, solo) **11d** (Laid-back, w/ Backing Track)	*a*	$_{OB}$*15*	Late snare flam	The early snare flams against the on-beat hi-hats are rather evident in comparisons of the laid-back and on-beat performances, both in a solo context (11a and 11c) and against the backing track (11b and 11d).
12a (On, solo) **12b** (On, w/ Backing Track) **12c** (Pushed, solo) **12d** (Pushed, w/ Backing Track)	*t*	$_{OB}$*7*	General earliness	In the metronome condition, the earliness of all the drum instruments is not as apparent in a solo context when comparing on-beat and pushed performances (10a and 10c). However, when heard with the backing track, the consistent pushing of all the drums against guitar and bass becomes clearer (10b and 10d).
13a (On, solo) **13b** (On, w/ Backing Track) **13c** (Pushed, solo) **13d** (Pushed, w/ Backing Track)	*l*	$_{OB}$7	General earliness + early kick flam	When comparing the solo pushed and on-beat performances (13a and 13c), the early kick flams can be heard pushing slightly against the hi-hats on beats 1 and 3 in the pushed performance. Against the backing track (13b and 13d), we also hear the early kicks, but more against the attacks of the bass strokes than against those of the hi-hats, which become masked to some extent.
14a (On, solo) **14b** (On, w/ Backing Track) **14c** (Pushed, solo) **14d** (Pushed, w/ Backing Track)	k	$_{OB}$*6*	Early kick/snare + late hi-hat flam	In the on-beat performances, both solo and with backing track (14a–b), we can hear that all of the drums are more tightly synchronised with each other and the bass/guitar sounds than they are in the laid-back performances (14c–d), where the snare and kick flam against the hi-hats in the solo context, and the guitar and bass against the backing-track.

Note: P. = Participant.