Timing Asynchrony for Maximal Groove

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Groove is a pleasant feeling that compels people to move their bodies along with music. In the past, there was some consensus among both musicians and researchers that the main factor in inducing this feeling is onset asynchrony of sounds. However, recent studies have asserted that no-asynchrony is the condition that will obtain the highest groove. In the current study, we measured the groove increment of a backbeat drum pattern as a function of the asynchronies between the bass guitar and hi-hat cymbal sounds. Upon evaluation, the scores of no conditions exceeded the condition with equal score to the condition with complete synchrony, and that score was higher than the ones achieved with slight bass guitar pre-delay. In Experiment 2, we measured the participants’ sensitivities to timing discrimination. The results confirmed that the amount of bass precedence in Experiment 1 was perceptible to the listeners. These findings suggest that complete synchronization is not always the best condition to achieve groove and that listeners prefer perceivable asynchronies in some cases.

Received: September 3, 2014, accepted January 14, 2016.

Key words: timing asynchrony, groove, drum and bass, backbeat, timing discrimination

A sense of “groove” is a pleasant feeling that compels people to move their bodies in synchrony to music (Davies, Madison, Silva, & Gouyon, 2013; Janata, Tomic, & Haberman, 2012). This is one of the fundamental elements for music enjoyment. Accordingly, many researchers have explored the factors that induce and enhance groove (see Janata et al., 2012, and Madison, Gouyon, Ullén, & Hörnström, 2011, for reviews).

Small timing asynchrony between the beats of instruments has been assumed to be one of the main factors that produce the feeling of groove. Most studies asserting a positive effect of asynchronies on groove stem from Keil (1966). Keil argues that asynchronies within a music rendition performed by skilled musicians are somewhat “syntactic” (i.e., not random) and reflect interactions between the players. According to Keil, an “on-top” playing style, in which the beats are tightly synchronized with other instruments or are executed ahead of the others, conveys a “push” feel. Conversely, a “lay-back” style, in which the beats are delayed loosely with respect to others, conveys a “pull” feel. Keil maintained that sensations arising from the push-pull interaction induce the feelings of “oneness,” “participation,” and groove. Keil (1966) often used the word “swing” instead of “groove,” but in his later work (Keil, 1987) he noted the two were conceptually the same. With empirical data, Prögler (1995) supported Keil’s idea. He had musicians perform a groove-oriented rendition, and his acoustical analysis showed the existence of syntactic asynchronies. Prögler also found there were some styles of usage of the syntactic asynchronies; some players preferred either on-top or lay-back, while others switched the two styles back and forth. Although Keil and Prögler did not discuss the perceptual mechanism in detail, there has been a certain history of many musicians agreeing with their insights (Iyer, 2002; Keil, 1966; Keil, 1987, 1995; Keil & Feld, 1994; Prögler, 1995).

Recent well-controlled empirical studies, however, are skeptical of the positive effect of asynchronies on groove (but, see Kilchenmann & Senn, 2015). Madison et al. (2011) computed the correlation between the amount of asynchronies and the intensities of groove using hundreds of music excerpts from various genres. As a result, they did not find any significant correlation between asynchrony and groove. Subsequently, Davies et al. (2013) tested the influence of asynchronies in jazz, samba, and funk, using controlled stimuli in which the timing asynchronies were systematically manipulated. The results showed a broad tendency for groove to decrease as asynchronies increased. Further, Frühauf, Kopiez, and Platz (2013) examined the influence of timing asynchronies in a pop-oriented drum pattern. They manipulated the onset timing of the snare drum or bass drum with respect to that of the hi-hat cymbal by either...
-25 ms, -15 ms, 0 ms, +15 ms, or +25 ms; the direction and the amount of asynchronies did not vary during a stimulus. In their results, the highest groove occurred in the 0 ms condition. The findings of these studies are contrary to the arguments of Keil and his colleagues.

Butterfield (2010) offers a compromise that proposes a limited effect of timing asynchronies on groove. He is basically unconvinced that timing asynchronies enhance groove because the asynchronies in actual music are small as most people can hardly perceive them. However, in his general discussion, Butterfield also mentions the possibility that asynchrony would elicit the desire to "catch up" with the beat. He did not regard this catch-up feeling as a groove per se, but he supposed it might be related to the momentum of groove. Therefore, it is still unclear whether timing asynchronies have a positive influence on groove perception; there are several standpoints regarding the effectiveness of asynchronies.

The aim of this study is to examine whether no-asynchrony is the best condition to elicit groove. To this end, we analyzed two aspects of the data. The primary aspect was the groove intensity increment. While the analysis of this aspect is not unique to this study, we do employ some important distinctive techniques. First, we used pairwise comparisons for groove evaluation. Pairwise comparison is a well-established method in psychophysics and is suitable for measuring ambiguous psychological quantities. Second, we used a pop-oriented backbeat drumming pattern for the stimuli, following Frühauf et al. (2013). It is known that groove is correlated with familiarity (Janata et al., 2012), and the backbeat pattern would be familiar to the young adult participants in our experiment. Third, we manipulated the asynchronies between the bass guitar and drum. The intention of this manipulation was to enhance the sensation of groove by assuming an interaction between the players (a bassist and a drummer).

The secondary aspect of the data we analyzed was the mean value of the magnitude of asynchronies that conveyed the best groove score. This value can be regarded as the center of the groove distribution as a function of asynchrony and, thus, representative of the asynchrony eliciting the highest groove. Therefore, results indicating that this value is not 0 would cast doubt on the assumption that no-asynchrony is the best condition for groove. To allow us to measure the direction and amount of asynchrony for the best groove, we did not change the variables during each stimulus: The asynchrony did not go back and forth between push and pull, but was maintained as either ahead, on-top, or lay-back. Furthermore, in Experiment 2, we measured our stimulus’s point of subjective equality (PSE) and asynchrony thresholds, at which the listeners were able to discriminate the preceding instrument. With this test, we ruled out the possibility that the beats presented with asynchrony appear to be synchronized for the listeners. Frühauf et al. (2013) have already briefly mentioned that the distribution of the quality of drum patterns as a function of asynchrony is not symmetrical around 0 ms (no-asynchrony). However, they did not assess the location of the center of the distribution. In addition, they did not measure the participant’s sensitivity to asynchronies.

**Experiment 1**

**METHOD**

**Participants.** Forty Osaka University students (21 males, 19 females), aged $M = 22.65$ (SD = 1.00) years, participated in the experiment. All participants self-reported normal auditory acuity. (Of the participants, 11 males and 9 females self-reported that they had a history of music lessons and/or other habitual music activities in addition to that of compulsory education. However, we chose not to discuss the influence of music experience since we did not find any evidence that this would affect our results.) All participants provided informed consent.

**Stimuli and apparatus.** The stimulus was a backbeat drum pattern that was accompanied by the repetitive bass and hi-hat cymbal in eighth notes (Figure 1). The length of the pattern was four bars with a tempo of 120 bpm; the first bar was an introduction and the last bar was a rest. The stimuli were created using CUBASE 5 (Steinberg Media Technologies GmbH); the drum and electric bass guitar sounds were generated with the Dry Standard Kit and Precision Round Wound sound instrument sets that were included with the software (hereafter, “bass” is used to mean an electric bass guitar, not a bass drum). The pitch of the bass sound was 130.82 Hz. The onset timing of the bass sound was uniformly delayed with respect to that of the hi-hat cymbal sound; the inter-onset interval of the bass was isochronously 250 ms, as

![Figure 1. Bass guitar sound and drum pattern. The bass guitar sounds were executed with uniform asynchrony with respect to the hi-hat cymbal.](http://www.license-plate.org/magazine/images/final-figure1.png)
was that of the hi-hat cymbal. The corresponding beats within the drum set (hi-hat cymbal, snare drum, and bass drum) were always synchronized. Seven levels of bass delay were used for our stimuli: $-62.50$ ms, $-46.88$ ms, $-31.25$ ms, $0$ ms, $31.25$ ms, $46.88$ ms, and $62.50$ ms. These lengths correspond to $-4/32$, $-3/32$, $-2/32$, $0/32$, $2/32$, $3/32$, and $4/32$ beats; the length of a $32/32$ beat was $500$ ms because the tempo was $120$ bpm. The range of the seven levels was decided based on a pilot experiment; the participants in the pilot were able to identify the preceded/delayed instrument in almost all trials when the asynchrony was larger than $\pm 4/32$ beat. Note that negative values of delay indicate the precedence of the bass. We did not use the levels of $-15.63$ ms ($-1/32$ beat) and $15.63$ ms ($1/32$ beat) because Butterfield (2010) reported that most participants were unable to explicitly identify a discrepancy of $30$ ms. To cue the beginning of the stimulus, the high-hat cymbal was executed four times in quarter notes during the first bar. This introduction also enabled us to discriminate delay of bass from precedence of drums. Participants were instructed to ignore the introduction when making evaluations. The stimuli were presented using a computer (Apple, iPad mini) and headset (Sony, MDR–NC600D).

**Evaluation items.** We used four evaluation items: (a) “feeling of drive to move your body parts along with the music,” (b) “feeling of pleasantness because of the music,” (c) “feeling as if you are moving forward along with the music,” and (d) “unnaturalness of the music.” Items (a) and (b) were intended to measure groove. Item (c) was intended to measure another type of motion sensation. Item (d) was intended to assess the sensitivity of the participants to the asynchrony. Hereafter, we refer to these items as Motion Drive, Pleasantness, Forward Motion, and Unnaturalness.

**Procedure.** The experiment was conducted individually. Each participant adjusted the width of the headset and the volume of the music by listening to a sample sound. The sample sound was the same as the stimulus for the $0$ ms asynchrony condition. After the adjustments, the main session was started. Two stimuli were presented in each trial. After the presentation of the first stimulus (we refer to this as $A$), which was followed by silence for $2$ s, the second stimulus (we refer to this as $B$) was automatically presented. Participants were instructed to “compare stimuli $A$ and $B$, and identify the stimulus for which you perceived a greater magnitude for the evaluation item. Then, state the difference in magnitude between $A$ and $B$.” Responses were collected using a visual analog scale (VAS; see Figure 2). Although there were small line segments that divided the scale into four parts, participants were allowed to mark their response anywhere on the scale. The line segments were accompanied by the labels as follows: “clearly $A$,” “somewhat $A$,” “equal,” “somewhat $B$,” and “clearly $B$.”

In a trial, if the reference stimulus is presented first, followed by the deviant stimulus, then $A$ is the reference stimulus and $B$ is the deviant stimulus. In this case, the scores of “clearly $A$,” “somewhat $A$,” “equal,” “somewhat $B$,” and “clearly $B$” are $-50$, $-25$, $0$, $25$, and $50$ respectively. However, note that the participants were allowed to mark anywhere on the horizontal line.
FIGURE 3. Score as a function of the extent of asynchrony for each evaluation item: (a) Motion Drive, (b) Pleasantness, (c) Forward Motion, and (d) Naturalness. Note that the negative values on the abscissa indicate the bass precedence. The error bars indicate standard errors.

The evaluation scores as a function of asynchrony are shown in Figure 3; the approximate shape of the curve of the function was an inverted U for all evaluation items. A one-way ANOVA for each evaluation item showed the statistical significance of the asynchrony, $F(6, 234) = 25.98, p < .001$ for Motion Drive; $F(6, 234) = 41.73, p < .001$ for Pleasantness; $F(6, 234) = 15.00, p < .001$ for Move Forward; and $F(6, 234) = 45.90, p < .001$ for Naturalness. Multiple comparisons (Ryan’s method with .05 alpha level) for Motion Drive indicated that the scores in the $-31.25$ ms and 0 ms conditions were higher than those in the other conditions, but the difference between the scores in $-31.25$ ms and 0 ms conditions was not significant. Multiple comparisons for Pleasantness indicated that the scores in the $-31.25$ ms and 0 ms conditions were higher than those in the other conditions, but the differences among the scores in the $-62.5$ ms, $-46.88$ ms, $-31.25$ ms, and 0 ms conditions were not significant. Multiple comparisons for Naturalness indicated that the scores in the $-31.25$ ms and 0 ms conditions were higher than those in the other conditions, but the difference between the scores in the $-31.25$ ms and 0 ms conditions was not significant. Multiple comparisons for Move Forward indicated that the scores in the $-62.5$ ms, $-46.88$ ms, $-31.25$ ms, and 0 ms conditions were higher than those in the other conditions, but the differences among the scores in the $-62.5$ ms, $-46.88$ ms, $-31.25$ ms, and 0 ms conditions were not significant. Multiple comparisons for Naturalness indicated that the scores in the $-31.25$ ms and 0 ms conditions were higher than those in the other conditions, but the difference between the scores in the $-31.25$ ms and 0 ms conditions was not significant. The general tendency of these results was similar to that of Frühaufl et al. (2013), in which the quality (corresponding to groove) as a function of asynchrony was not symmetrical about 0 ms condition and no asynchronies enhanced the groove. However, in our results, the evaluation scores plateaued around the $-31.25$ ms and 0 ms conditions, instead of an obvious decrement that was demonstrated in Frühaufl et al. (2013).

For the analysis of the secondary aspect of the data, we computed the means of the highest evaluated asynchrony magnitudes. At first, we extracted the asynchrony of a condition whose score was the highest within each
When there were two identical highest scores, the mean of the two asynchronies in those conditions was used. The histograms of the extracted asynchronies from the participants are shown in Figure 4. Next, we calculated the mean of the asynchronies across the participants. This was equivalent to the center of the plateau of the function curve. The mean asynchronies for the highest Motion Drive, Forward Motion, and Pleasantness were $10.78 \text{ ms (SD } = 28.28)$, $23.31 \text{ ms (SD } = 33.59)$, and $8.98 \text{ ms (SD } = 25.47)$, respectively, which were all statistically different from 0 ms, $t(39) = 2.42$, $p = .02$; $t(39) = 4.39$, $p < .001$; and $t(39) = 2.23$, $p = .03$, respectively. However, the mean for Naturalness was $3.90 \text{ ms (SD } = 26.40)$, which was not significantly different from 0, $t(39) = 0.92$, $p = .36$. These results indicate that the center of the asynchronies that convey the highest groove (i.e., Motion Drive and Pleasantness) was not 0 ms.

Although the intensity of groove (Motion Drive and Pleasantness) was not enhanced by asynchrony, some bass-preceding conditions were evaluated as being as groovy as the synchronous condition, which was preferred in almost all other conditions. Further, the center of the distribution of asynchronies with higher scores was biased toward the bass-precedence side. These results indicate that complete synchrony is not always the best condition in terms of groove. Interestingly, the mean asynchrony for the best score of Naturalness was not significantly shifted from 0 ms. This exception suggests that it is the meaning of the evaluation items that conveyed the bias, rather than a meaningless selection of slight-bass-precedence stimuli.

One curious point of our results is the broadness of the plateau for the Forward Motion score. In Forward Motion, unlike the other evaluation items, the score was almost the highest even in the $-62.50 \text{ ms}$ condition; the
listeners must be able to sense such a large asynchrony (see also Experiment 2). This result does not mean that Forward Motion is independent of asynchrony, as is clear from the asymmetrical distribution in which the plateau as the highest score was observed only in the bass precedence and synchronous conditions. The mechanism by which the bass precedence retained the feeling of Forward Motion is still unclear. However, perhaps some kinds of asynchrony, such as the constant delay/precedence that we used, may be strongly associated with locomotion (Forward Motion) rather than tapping or bobbing motions (Motion Drive). Further studies are needed to clarify the mechanism that explains the relationship between asynchronies and Forward Motion.

However, to be able to assert that the asynchronies affected the groove evaluation, we have to clarify the listener’s sensitivity and PSE for asynchronies. If the PSE of asynchronies in which the listener perceives a perfect synchronization of the two sounds is equivalent to the center of the plateau (i.e., approximately 10 ms), Experiment 1 merely indicates a simple tendency for listeners to prefer the subjective synchronization. The asynchrony in this study was manipulated based on objective onset timing that was defined by the computer software (CUBASE 5). Therefore, it is unclear whether the asynchrony was actually perceived by the listeners as an asynchrony. In Experiment 2, in order to examine this possibility, we measured the PSE and thresholds for the onset timing of the bass and drum sounds.

Experiment 2

In this experiment, we measured the PSE and thresholds of the onset timing asynchrony between the bass and drum in our stimuli. For the measurement of these values, we employed the method of constant stimuli, which is popular in the field of psychophysics.

METHOD

Participants. Sixteen Osaka University students (nine males, seven females), aged $M = 22.06$ (SD = 0.21) years, participated in the experiment. All participants self-reported normal auditory acuity. (Seven males and two females self-reported that they had a history of music lessons and/or other habitual music activities aside from that of compulsory education.) All participants provided informed consent.

Stimuli and apparatus. The stimuli and apparatus were identical to those used in Experiment 1.

Procedure. One stimulus was presented in each trial, unlike Experiment 1. The participants were asked to identify which of the bass and drum had been executed earlier in a series of beats. Participants responded by circling either “bass” or “drums” on a sheet of paper. Each of the seven levels of asynchrony was replicated eight times. Hence, the main session was composed of 56 trials. The trial order was randomized. Before the main session, we presented all the levels of the stimuli to the participants in ascending order (i.e., from $-62.50$ ms to $62.50$ ms) and informed them that they would encounter these stimuli.

RESULTS AND DISCUSSION

We first calculated the probability of the “drum” response as the preceding instrument. This probability was calculated for each asynchrony level within each participant. The data of three participants were excluded from further analysis because the probability of the correct responses did not reach 75% in the easiest conditions ($-62.50$ ms or $62.50$ ms), indicating their inappropriate performance. With this exclusion, the ICC2 as inter-rater reliability was enhanced from .67, $F(6, 90) = 30.00, p < .001$, to .82, $F(6, 72) = 58.00, p < .001$. The shape of the probability function of the asynchrony was approximately sigmoid, in which the probability increased as the bass delay increased. The mean probabilities across the participants for the conditions of $-62.50$ ms, $-46.88$ ms, $-31.25$ ms, $0$ ms, $31.25$ ms, $46.88$ ms, and $62.50$ ms were $.05$ (SD = .08), $.10$ (SD = .15), $.25$ (SD = .14), $.38$ (SD = .19), $.71$ (SD = .25), $.83$ (SD = .17), and $.92$ (SD = .12), respectively (Figure 5).

Next, to compute the value of the 25% point (lower threshold), the 50% point (point of subjective equality;
PSE), and the 75% point (upper threshold), we fitted a Gaussian function to the empirical data (i.e., the probability of “drum”) for each participant, using the least square method. Table 1 shows the means of these values.

The PSE of 9.24, 95% CI [2.12, 16.36], indicated that the listeners perceive an unbiased synchronization of bass and drums when the bass sound occurred after the drum. This result verified that the preference of bass precedence for the highest groove, which was found in Experiment 1, was not equivalent to PSE. Interestingly, while the asynchrony of the −31.25 ms condition (bass precedence) is perceptible, that of +31.25 ms (bass delay) is inside the interval of uncertainty. This result indicates that the listeners preferred a perceptible asynchrony more than an imperceptible asynchrony when they evaluated the quality of music in Experiment 1.

The loudness and timbre of the instruments may explain the non-zero PSE. Goebel and Parncutt (2002) demonstrated that the PSE for onset timing of two tones depends on the complexity of the tone (timbre) and the intensity ratio of the two tones.

**General Discussion**

We demonstrated that a slightly preceding bass line sounds as groovy as the synchronous rendition even when the listeners are aware of such timing asynchronies. However, it is also true that we could not find a condition that significantly enhanced the groove. Taken together, it seems that our findings correspond to what Butterfield (2010) implied rather than to Keil’s (1996) claims.

Our results suggest that, in terms of groove, it is not optimal to eliminate the asynchronies from your backbeat renditions: aiming for 10 ms of bass precedence would be better. It is true that the asynchrony in our experiment did not enhance the groove. However, aiming for complete bass-and-drum synchronization entails a risk that some sounds decrease from the plateau. In our results, the complete synchronization (0 ms) was around the edge of the plateau, while approximately 10 ms of bass precedence was the center of the asynchronies for the highest groove. If a bassist tries to execute his sound with 0 ms asynchrony with respect to the drum, approximately half of the sounds should be executed after the drum because of motor deviations, and those sounds would correspond with less groove. However, if s/he aims for 10 ms of bass precedence, the sounds may distributed around the center of the plateau and may tend to occur on the plateau, even if the timing is somewhat deviated. Therefore, to aim for a small asynchrony has a stochastic advantage in which the sounds tend to occur at the highest level of groove.

Why were the listeners more tolerant to the perceptible bass precedence than to the imperceptible bass delay? We speculate that there were two individual mechanisms, which keep the highest Motion Drive and Pleasantness, respectively.

An error correction tendency of individuals may be the mechanism that keeps the highest Motion Drive. Previous studies have shown that people tend to automatically correct unintended asynchronies when they perform rhythmic renditions (Repp, 2000, 2002). In the context of our experiment, it is likely that the preceding bass sound with respect to the drum beat (or to the listeners’ expectation that was formed from the introduction) induced a feeling that the listener’s internal rhythm was delaying. Then, such feelings might “nudge” the listeners to “catch up” with the preceding sound; this explanation follows the suggestion by Butterfield (2010). Our finding regarding Forward Motion, in which the highest groove was retained even with larger asynchronies, further supports this account; the concept of catch up may be strongly associated with moving ahead.

A misattribution of the cause of Motion Drive may be the mechanism that retains Pleasantness. Generally, in everyday life, it is a groovy situation in which an individual wants to move her/his body along with music. Therefore, it is likely that the listeners could have misunderstood the reason for the drive and perceived an illusory groove. It is well known that people often misattribute the reasons for their internal activity to relative things (Storms & Nisbett, 1970; Zillman, Katcher, & Milavsky, 1972).

As another explanatory candidate, a synchronization of the listeners’ actual motion and preceding bass sound may be the mechanism that retains Pleasantness. People

**TABLE 1. Estimates of the Thresholds and PSE for Onset Timing Asynchronies**

<table>
<thead>
<tr>
<th></th>
<th>Lower</th>
<th>PSE</th>
<th>Upper</th>
<th>SD</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>−19.37</td>
<td>9.24</td>
<td>37.84</td>
<td>42.41</td>
<td>0.88</td>
</tr>
<tr>
<td>95% CI</td>
<td>[−34.82, −3.91]</td>
<td>[2.12, 16.36]</td>
<td>[24.19, 51.49]</td>
<td>[23.54, 61.27]</td>
<td>[0.79, 0.96]</td>
</tr>
</tbody>
</table>

Note. N = 13. CI = confidence interval. SD is derived from a fitted Gaussian function.
tend to tap tens of milliseconds earlier with respect to tones when making repeated tapping motions along with rhythmic tones; such asynchrony is called negative mean asymmetry (NMA; see Repp, 2005; Repp & Su, 2013). Importantly, tapping with such precedence is judged by the tappers themselves as better synchronized than tapping with objective synchronization. Although we did not ask our participants to tap, some spontaneous motions, such as head bobbing, might have been synchronized with the preceding bass sound. Thus, it is possible that such synchronizations produced a pleasant feeling (Janata et al., 2012). However, it is also known that NMA is almost absent when a stimulus includes a complex music structure (Dixon, Goebl, & Cambouropoulos, 2006; Repp, 2008). Further studies are needed to clarify the mechanism that explains the relationship between bass precedence and highest groove.

There are two remaining issues that were not sufficiently examined in the current study. The first issue comprises stimuli familiarity/boredom in Experiment 1. The participants were frequently exposed to the 0 ms stimulus because it was also used as the reference stimulus in every trial. It is likely that the participants experienced familiarity with the 0 ms stimulus because of the repetition. If this was the case, the true intensity of groove for the 0 ms condition should be lower than the magnitude we obtained. The mere exposure effect (Zajonc, 1968) is a well-known and well-replicated phenomenon. In contrast, it is also possible that the participants became bored with the 0 ms stimulus. If so, the true intensity of groove for 0 ms condition should be higher than the one we obtained. Note that even if the true intensity of groove for 0 ms was higher than the one indicated in our study, the listeners’ preference for bass precedence over bass delay still holds since the score at −31.25 ms was higher than the score at +31.25 ms.

The second remaining issue was regarding groove intensity at the center of the plateau. Precisely, the actual shape of the plateau is unknown because the scores of the flat part were not directly measured. If the shape of the plateau is completely flat, the groove intensity would be the same as those in the −31.25 ms and 0 ms conditions. However, if the plateau is smoothly rounded, the intensity at the center would be slightly higher than those at −31.25 ms and 0 ms (Figure 6) since the logical value of the groove at 0 ms is 0 and the value at the rounded top should be higher. If that is the case, the shift of the center from 0 ms will be an indication of the positive influence of asynchrony on groove. Readers who are interested in the enhancement of groove with asynchrony should use smaller steps of the asynchrony for the conditions than the ones we used, so that one of the conditions matches the center of the plateau. However, even when an enhancement is obtained with this method, the degree of the enhancement will not be very large, based on an estimation from the whole shape of our function curves. In those cases, careful discussion is required to determine whether such small increments in the score reflect a lively sensation of groove.

This study demonstrated that a complete synchrony is not the only condition that induced the highest groove, as some timing asynchronies are also capable of this, even when the asynchronies are perceptible. The findings imply that the problem of timing asynchronies for groove has yet to be fully addressed.

**Author Note**

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