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Auditory Masking and the Precedence Effect in Studies of Musical Timekeeping

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ABSTRACT

Musical timekeeping is an important and evolving area of research with applications in a variety of music education and performance situations. Studies in this field are often concerned with being able to measure the accuracy or consistency of human participants, for whatever purpose is being investigated. Our initial explorations suggest that little has been done to consider the role that auditory masking, specifically the precedence effect, plays in the study of human timekeeping tasks. In this paper, we highlight the importance of integrating masking into studies of timekeeping and suggest areas for discussion and future research, to address shortfalls in the literature.

CCS CONCEPTS

• Applied computing~Sound and music computing • Applied computing~Performing arts • Human-centered computing~Sound-based input / output

KEYWORDS

Precedence effect, Haas effect, music, timekeeping.

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1 Introduction

Multiple fields of music research, training, performance, and recording, involve timekeeping. Principally, it is common to carry out activities that require human participants to play along to a metronome. For example: timekeeping ability may be under investigation from a psychology or neuroscientific perspective [1-4]; music students may be learning about the importance of time and rhythm in their studies [5-6]; or musicians may play along to a click track during a live performance or in the recording studio [7-10]. As such, the activity of playing to a clock, with fixed distance epochs, is a fundamental element within the practice of music. Improving understanding of this activity is the subject of much research [11-14] and this article aims to contribute to that discussion.

Specifically, we believe that little attention has been given to the role that auditory masking [15-16], particularly the precedence, or Haas, effect [17-18], might play in the study of human timekeeping. The Haas effect is an example of sensory inhibition, whereby the arrival of one sound masks the arrival of a second. Haas describes a window of sensory inhibition of approximately 25-35 milliseconds before two distinct sounds are detected, even if the level difference between the two is as high as 10 dB. To address this deficit, we highlight the importance and relevance of auditory masking to timekeeping practice and pose a number of questions, along with a justification of their relevance, that might be considered for future research studies in the field.

The remainder of this work is organized as follows: in Section 2 we provide a short summary of work relating specifically to the investigation of auditory masking effects with respect to isochronous signals. Specifically, we identify that the work discovered in this domain is minimal, but what little has been done shows that the precedence effect has relevance in this situation. In Section 3 we provide descriptions and definitions of typical timekeeping-related tasks, methods, and how these are likely to be influenced by the occurrence of auditory masking effects. We then present a series of questions and points for discussion that we hope highlight the importance of being able to understand and adjust for auditory masking when dealing with timekeeping tasks and research. This is furthered by a discussion of a proposed area for future work, which would seek to investigate how masking effects may, or may not, be interwoven with timekeeping ability. Finally, we present a short summary of this article and its implications to the field of timekeeping research.

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2 Related Work

To our knowledge, there have been no studies that have expressly investigated the impact that auditory masking and the precedence effect has on measuring timekeeping in human participants. However, the issue has been identified as a potential phenomenon in other work [19] relating to teaching and learning of rhythm, certainly as an issue of temporal and frequency auditory masking. In particular, it is postulated that students will adjust their playing so that they might hear their own instrument distinctly from the metronome click. However, the precedence effect is not dealt with specifically.

Other work [20] investigated the manifestation and perception of the precedence effect in click trains, which are sustained isochronous patterns. These authors explored the localization effect experienced by listeners where a leading and lagging sound are presented in the left and right channels, separated by short delays. They investigated the effects that switching the leading click, between left and right channel had on listeners' abilities to localize the source and their perception of echo artefacts, rather than the experience of a single, fused source. It was found that when interaural lag and delay configurations were switched, the echo suppression effect was temporarily inhibited, meaning both clicks were heard. The time taken for the echo suppression to be reinstated was a function of the delay time between the leading and lagging click: shorter delays led to quicker reinstatement of echo suppression. These findings not only identify that the precedence effect is a phenomenon that can occur in situations where transient clicks are used, but also that direction switching would temporarily lead to the breakdown of the precedence effect; a situation that could feasibly occur when a musician was playing with other musicians around them, such as in an orchestra, ensemble, or contemporary band.

3 Timekeeping, Auditory Masking and the Precedence Effect

3.1 Masking and its relevance to Timekeeping

With relevance to studies around musical timekeeping, the potential masking issue can be clarified. For example, Figure 1 illustrates the spectra of typical sounds encountered in timekeeping experiments. Specifically, it shows scope for frequency and temporal masking to occur given the wide spectral range and transient nature of the participant cowbell strikes and the isochronous, or monorhythmic, metronome. The polyrhythmic metronome also has transient spikes, but the addition of other sound events between the dominant beats means that the majority of the low to mid-range frequency bands exhibit a profile akin to noise. A pair consisting of a cowbell strike and one of the metronomes occurring simultaneously, or within short delays of one another, will give rise to masking being perceived by the person playing along, particularly in the case of the polyrhythmic metronome.

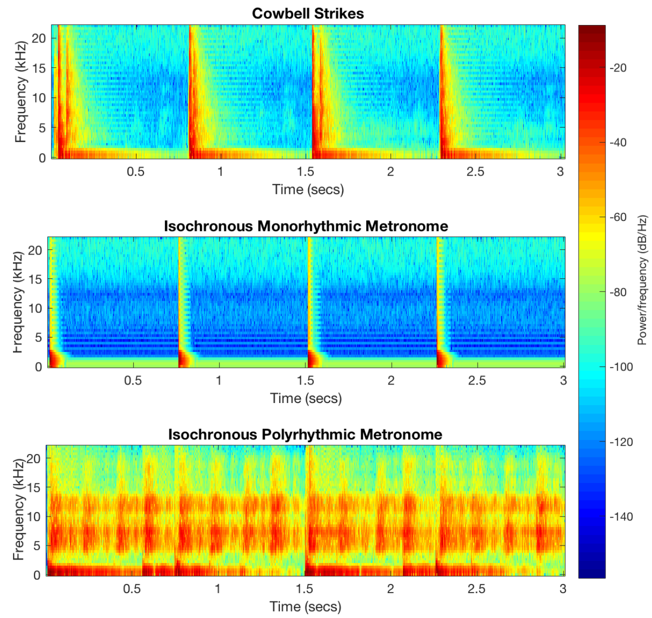

Figure 1: Spectra of Sound Events in a Timekeeping Study. 4 beats are illustrated in several conditions: Strikes of a Cowbell by a participant (top); Isochronous, Monorhythmic Metronome (middle); Isochronous, Polyrhythmic Metronome (bottom).

The activity of playing in time is simple and one that is understood from an early age, when children are encouraged to clap their hands in time with a presented musical stimulus. In formal education situations, this process is also followed, where a trainee musician will be required to perform with an instrument in time with a metronome. It is this aspect that we are concerned with, since the process sets the participant the task of having to mask the pulse of a metronome by producing a note.

Figure 2 illustrates a graphical example of two performers P, Player A and Player B, attempting to keep time with an isochronous metronome, operating at some fixed rate Δ.

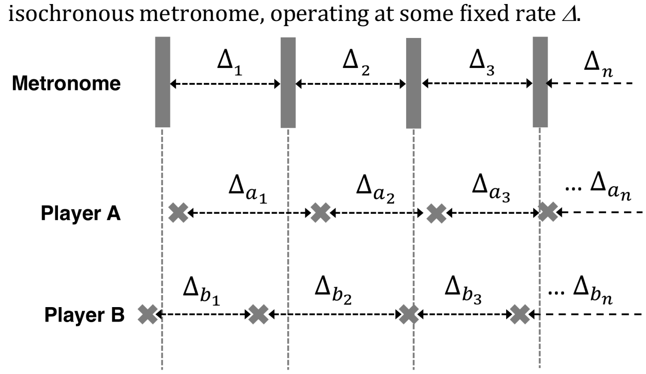

Figure 2: Metronome pulse and performances. Player A illustrating the post-masking phenomenon and Player B illustrating the pre-masking phenomenon.

In timekeeping evaluations, it is typical to ascertain each performer's timekeeping ability by measuring the distances between their strikes to the respective click $|\Delta_i - \Delta_{P_i}|$. Good timekeeping would be considered the ability to minimize this distance, whilst performers striking consistently after the click would be considered as dragging, as illustrated by Player A in Figure 2. Performers striking consistently in advance of the click would be considered rushing, as illustrated by Player B of Figure 2.

Another common measurement would be the consistency of a performer. Given the isochronous nature of the metronome, this provides an *expected* Inter-Onset Interval (e-IOI), which is fixed. This may be compared to the *performed* IOI (p-IOI) of a performer to determine their consistency, typically by comparing their mean p-IOI $\overline{\Delta_P} = \frac{\Delta_{P_n}}{n}$ over a fixed duration. It should be noted that in measuring consistency we may, or may not, be interested in whether or not the player is able to strike simultaneously with the metronome click.

With respect to both of the analysis tasks mentioned above, the click of the metronome provides an important anchor. In undertaking either, or both, of these tasks, we advocate that it is necessary to adjust for any masking effect that has taken place. For instance, if we consider the dragging exhibited by Player A or rushing of Player B, we need to be clear whether or not these deviations are a result of their ability to respond to the metronome or if this has been caused by their auditory masking threshold or Haas window. In the case of Player A, the lag may be caused by the metronome masking their own strike and thus being perceived as a single sound event, whilst in Player B we see the opposite situation where their strike could be masking the metronome and hence both are perceived as a simultaneous event. Further, we suggest that the adjustment required is likely to vary somewhat between individuals, since each person's perception of auditory stimuli are a function of their neurological and physical features.

3.2 Questions and Implications

We propose that investigating the Haas window of performers in timekeeping situations will lead to increased validity when analyzing their data, with possible benefits that would follow in the field of musical education and training, in particular. The following questions, and associated justification, are suitable areas to develop this initiative further.

3.2.1 How can an individual's Haas window be measured? A number of empirical studies have been conducted that examine the characteristics of auditory masking effects in human listeners. Classical studies in the field of temporal and frequency masking typically adopt controlled experimental studies with human subjects, where a variety of stimuli are presented with varying levels, temporal differences and tone bands. Responses from subjects are collected in response to these independent factors [21 to 25].

In the case of the precedence effect, an excellent summary is provided by Brown, Stecker and Tollin [26], who identify that the approach taken by most studies utilizes a simulation of directional sound sources, either through the placement of loudspeakers spatially around a listener or by requiring the listener to wear headphones. Delay times and attenuation between the leading and lagging signals can then be adjusted by the researcher and the effects of these delay times measured in participants of such studies. Specifically, the point at which a participant perceives two distinct sound sources occurring is the echo threshold and, for the purposes of our discussion, might be considered the maximum duration of a particular person's Haas, or spatial masking, window.

Based upon these established methods, which have shaped the fundamental understanding of human hearing and current psychoacoustic thinking, it seems suitable that a similar approach be adopted to measure Haas windows for the purposes of timekeeping studies, with the inclusion of practice from Clifton and Freyman [20] to allow for the isochronous nature of click trains to be accounted for.

3.2.2 Is there a difference in the size of a Haas window when sources are spatially distinct (simultaneous and temporal masking versus the precedence effect)? Addressing this question would allow for explicitly bridging the gap between the existing knowledge on non-directional and spatial masking, as outlined in the previous sub-section. These aspects are pertinent in the case of musical timekeeping since there may be occasions where a drummer, for instance, must play to a guide track via headphones or with a large group of musicians, giving rise to situations of directional and non-directional masking. For the purposes of musical education, and particularly the training of young or beginner musicians, it may be beneficial to develop a testing process that provides an approximate measure of a participant's Haas window, whilst using a less formal procedure than that of a laboratory-condition experiment. If the aim is to establish a link between musical timekeeping and the precedence effect, it may be beneficial to test musicians in a more realistic setting. A test methodology that frees musicians to perform in a more natural environment, whilst providing binaural cues, may offer the ability to measure an approximate Haas window of participants, whilst offering a more accessible test format (and potentially allowing access to a far wider pool of participants). This data could then be used in further, more formal testing. Participants can be measured in two test conditions: 1) audio stimuli provided over a stereo loudspeaker system; 2) audio stimuli provided over headphones. A comparison of these two sets of results may provide some insight into the correlation of participants' Haas window when sources are spatially distinct.

3.2.3 Do people who are better at playing to a metronome have different Haas window sizes to a control group? There are many examples of isochronous reproduction tests and tapping experiments, all of which use a similar procedure. We propose to use this common methodology to test a group of experienced, trained participants (e.g. high-level or professional musicians) and a control group of untrained participants. This methodology would allow confirmation of a difference in ability to produce accurate isochronous patterns when provided with a metronome (as well as measurements of an individual's Inter Onset Interval) from one group to the other. A measurement of individual Haas windows would then give sufficient data to establish any potential relationship between musical timekeeping accuracy and the size of an individual's Haas window.

3.2.4 Can the Haas window of an individual be adjusted through a training process? The answer to this question may lie in a long-term study. We propose the observation of musicians as they progress through increased levels of musical competency. If measurements of participants' Haas windows are taken at prescribed intervals then it may be possible to draw conclusions as to the effect increased musical proficiency has on the size of an individual's Haas window. It is important to consider the findings of Bernstein *et al.* [27] when collecting these measurements, as there are some conditions where procedural learning can influence a participant's ability over time.

3.2.5 What effect does shortening a person's Haas window have on their ability to reproduce an isochronous pattern? Assuming a Haas window can be shortened it may not necessarily follow that this has a direct correlation with the ability of a person to accurately reproduce an isochronous pattern without an audio stimulus. To measure this with any confidence, it would be necessary to conduct a long-term study that measured an initial ability to reproduce a pattern without a metronome present and compare it to a measurement taken after the Haas window had been shortened. If there is a correlation between Haas window size and the accuracy of a reproduced pattern, it may stand to reason that a participant's musical timekeeping can be positively influenced by the reduction of their Haas window.

4 Summary

We have shown that there is a distinct lack of information and empirical research that has investigated the relationship between various types of auditory masking and timekeeping tasks, such as tapping experiments, music education or performance scenarios. Illustrations are provided of the significance that auditory masking may play in timekeeping and rhythmic related activities and we have provided a series of questions and discussion points that we hope will help to shape future practice and research into this topic.

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