The influence of perception latency on the quality of musical performance during a simulated delay scenario

by

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A mini dissertation submitted in partial fulfilment of the requirements for the degree

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Pretoria
July 2016

Acknowledgements

First and foremost, I would like to thank my supervisor, Murray de Villiers, for his support during the research process. His guidance and life advice will always be remembered and is much appreciated.

I would also like to thank the following staff members at the University of Pretoria: Dr. Clorinda Panebianco-Warrens, for her open-door policy and allowing me to spend hours in her office performing research; Prof. Alexander Johnson and Prof. Wim Viljoen, for their support in getting the research proposal accepted.

I would also like to acknowledge all the study participants – without whom this study would not have been able to materialise – for their invaluable time, effort and contribution in studio.

Lastly, I would like to express my gratitude toward my parents for their unwavering support during this research project and for always pushing me to succeed.

Abstract

Audio perception latency can influence the performance ability of a musician. A phenomenographic study is conducted to discuss the issue of perception latency and determine the amount of latency musicians can tolerate. Potential contributing factors such as their musical training, studio experience, and ability to perform with a metronomic aid were taken into account. Upon completion of the performance aspect of the study, the researcher then conducted a semi-structured interview with each individual participant in which a series of questions were asked about the experiment.

It is found that musicians employ various techniques to compensate for perception latency and that there is a maximum amount of latency that musicians can tolerate during a musical performance.

Keywords: perception latency, reception latency, response latency, maximum latency, delay, optimal performance, tolerable performance.

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Terminology and concept clarification

ADSR envelope: An ADSR envelope (graph) describes the amplitudinal progression of sound production, as characterised by its inherent features relating to the attack, decay, sustain and release phases.

Articulation: The way of characterising successive notes by the precise control of their individual length to produce or eliminate gaps between them, creating musical phrases. (Wilkie 1997)

Audio delay: The temporal audio processing which comprises the recording of an input signal and the subsequent delayed rendered playback. (Reid 1999)

Audio level: For the purposes of this paper, the audio level will refer to the sound pressure level of sound and be measured in decibels (dB). (Randel 2003)

Latency: The total time that elapses between a message/command transmitted and the receiver/user executing an action, i.e. transmission latency + perception latency + response latency.

MIDI (Musical Instrument Digital Interface): A digital communication protocol that enables communication between digital music instruments. (Roland Corporation 2009)

Optimally: The term used to describe the criterion at which the musician can perform with the highest level of satisfaction.

Perception latency: The time that elapses between a message reaching the receiver/user and the receiver/user's neurological ability to perceive and interpret the message.

Response latency: The time that elapses between the receiver/user's neurological interpretation of a message and the ability to execute an action.

Tempo: The speed at which music is performed; measured in BPM (music beats per minute). (Randel 2003)

Tolerance: The term "tolerable" will be used for a situation in which a musician can accommodate interference and still perform optimally without having to adapt their musical performance technique.

Transmission latency: The time that elapses between the transmission of a message and the receipt thereof.

CHAPTER 1: INTRODUCTION

This chapter contains the background to the study and the reasons behind the researcher's choice of topic. It includes the motivation for the study, theoretical framework upon which the study is based, research questions addressed by this study, as well as study delimitations. Presented at the end of this chapter is an overview of the chapters in the study.

1.1 Background to the study

As a performing artist (pianist and singer/songwriter), the researcher has performed in numerous groups, most of which contemporary ensembles, and collaborated with other musicians online via various internet protocol software services, such as Skype[1]. Throughout these various performance scenarios, the issue of performance latency[2] was encountered. As music is mostly driven by rhythmic synchronicity, latency experienced during these scenarios negatively affects musical performance in several ways; for instance, it allows musicians to change the tempo and audio level of their performance, as well as influences performance musicality.

During a live performance, musicians who perform as part of a group rely on specific rhythmic cues to maintain tempo. An example of this is the use of a drummer to maintain a steady tempo throughout a performance. In this group environment, there can be a delay between the time a musician plays and another perceives the sound. This is chiefly due to the speed at which sound travels from the source to the observer (Boley & Lester 2007).

Live performance, however, is not an exclusive scenario wherein latency can be experienced. Current music technological practices involve, among others, digital processing and communication, which are inherently prone to electronic processing-induced delay. This is particularly evident in cases where complex digital audio processing is utilised in the music performance and production process. This signal processing delay can influence the ability of the musician to coherently perceive music. Additionally, the ability of an individual to respond to a musical cue can introduce a stimulus response delay.

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[1] Skype is a software application that enables users to communicate with each other via mobile phone or computer.
[2] Refer to the terminology section for definitions of key concepts.

1.2 Motivation for the study

There is a need to investigate the effect of latency on musicians, as well as the coping strategies that they might employ. By knowing what these coping mechanisms might be, musicians might be better able to adjust their performances or adapt to latency-induced scenarios. The aim of the researcher is to ascertain the maximum amount of latency that musicians can tolerate before performance is compromised. This could enable engineers who design and develop latency-producing equipment to better understand the effects of latency on musicians and what their limitations are. It may also aid musicians in acquiring a better understanding of the parameters and limitations that could affect their performances.

1.3 Theoretical framework

The core of this study evaluates the stimulus response of audio perception latency as experienced by performers in music production. This human response to an introduced phenomenon is characterised by what the subject (musician) experiences, thus necessitating a phenomenographic research approach.

Phenomenography is an empirical study of the different ways in which people observe and experience the various aspects of a specific concept (Ornek 2008). This investigation into the variation in people's interpretation and understanding of a concept, as opposed to the concept itself, is referred to as a second-order perspective (Holmstrom & Larsson 2007). Phenomenography relies on participants' discursive accounts of their individual experiences and uses semi-structured interviews for data collection (Richardson 1999).

A phenomenographic approach is therefore relevant to this study, since the researcher seeks to discover the various ways in which individual participants experience the different aspects of performance latency. This approach also pertains to the specific data collection method that the researcher has employed. By using semi-structured interviews, the researcher is able to guide the interview process whilst the participant reflects on his/her experiences.

1.4 Research questions

Main research question:
What is the maximum amount of latency that musicians can tolerate and how will this affect them when utilising latency-inducing technologies such as in-line audio processing?

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Sub-questions:

- *Can the debilitating effect of perception latency be compensated for during online music collaboration?*

- *To what extent will latency influence the musician's ability to perform optimally?*

- *Does the extent of the musician's music training influence his/her ability to compensate successfully for perception latency?*

- *To what extent can metronomic aids assist a musician to compensate for communication and processing-induced perception latency?*

1.5 Delimitations and value of the study

Perception latency is a potential problem that musicians may experience in various recording, performing and collaboration scenarios (which will be discussed in the literature review). The aim of the study is to establish the temporal debilitation threshold of perception latency-induced musical performance in musicians of different competency levels. Deviation from metronomic timing has been used as a measurement for performance accuracy.

The value of the study is to assist in making musicians aware of an alternative approach to their musical performance when encountering some form of perception latency. Musicians may also benefit from knowing their personal threshold of latency tolerance, to the extent that it might influence their musical performance. In addition, an understanding of how latency influences musicians may help audio engineers to design products that do not produce obtrusive latencies.

Whether the different types of latencies produce different effects on musicians is not in the scope of this study. In addition, the study is limited to individual participation and will not include more than one musician performing simultaneously. It is also not within the scope of the study to ascertain whether frequent exposure to latency may have an effect on latency tolerance. Moreover, the variables that could influence online music collaboration will not be discussed, as such a topic is broad enough to constitute a separate research paper.

1.6 Chapter outline

Chapter one outlines the background and value of the study. It also introduces the research questions, theoretical framework, as well as delimitations for the study. Chapter two presents the literature that is available on the topic and how other researchers have contributed to the

field of the study. Chapter three explains the methodology, research approach and design, sampling strategy, and ethical considerations for the study. It also sets forth the data analysis method employed for the study.

Chapter four presents the data collection processes as well as all the data collected during the experiments. It categorises the data according to the relevant research questions. Chapter five analyses the data collected and discusses the outcomes based on the research questions. It also discusses various causes for latency and how latency can be used for creative effect. Chapter six summarises the outcomes of the study, addresses the research questions and suggests possible areas for further investigation.

Lastly, the consent form for participation in the research study is attached as Appendix A, the interview schedule utilised for the experiments as Appendix B and the interview transcripts as Appendix C.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

A preliminary search on existing literature regarding the topic of discussion is outlined in this chapter, categorised under the following headings:

- Delay
- Audio perception latency
- The sound envelope
- Previous audio perception studies

2.2 Delay

In practical terms, delay is encountered in the form of either mechanical or digital processing delay. These types of delay, as well as the various causes of delay and its utilisation as an effect, are discussed in the following paragraphs.

2.2.1 Mechanical delay

Before digital delay units were created, engineers used audio tape recorders to create delays. There are still several audio engineers who prefer the use of analogue delay units as opposed to their digital counterparts. To understand how electronic delay units function, it is of value to discuss the fundamentals of delays through the utilisation of audio tape recorders as examples (Izhaki 2008:380).

A magnetic tape loop is used to delay the input signal of a source by a set amount of time. This is achieved by passing the tape through three heads, namely the erase head, the record head and the playback head (Figure 1). Firstly, the recording tape is cleared through erasing by an erase head, after which the input signal is then recorded by the record head. It will then take a set amount of time for the recorded material to move to the playback head, from where it will be sent to the output of the unit. The capstan is a pin that controls the speed. The delay time is determined by the time it takes for the signal to travel from the record to the playback heads (Izhaki 2008:381).
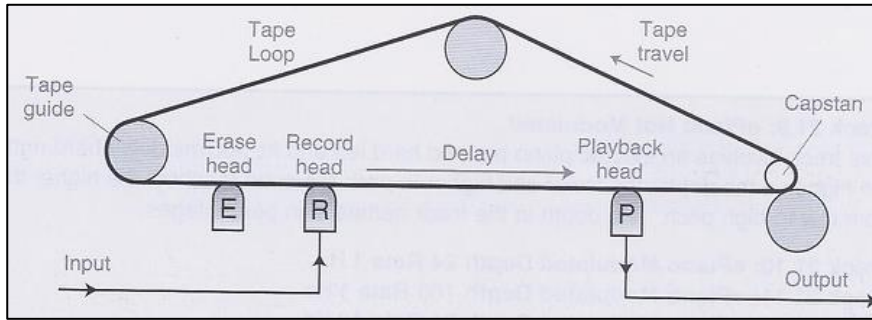
Figure 1. A basic tape loop (Izhaki 2008: 381).

The delay time can be controlled by either changing the distance between the record and playback heads or adjusting the tape speed. The delay time can thus be shortened or lengthened according to the user's requirements. The speed of the capstan can either be accelerated or slowed down; however, with consequential results. With a speed increase, the pitch will rise, and with a speed decrease, the pitch will drop. This can also be used for creative effect (Izhaki 2008:382).

To emulate multiple reflections from walls, repeating echoes can be created by using the tape recorder delay unit. To achieve this, the playback signal is routed back to the record head. This will create a feedback loop where each successive signal is routed back to the record head, thus causing a repetitive delaying of the signal (as seen in Figure 2). To control the amount of attenuation on repeating echoes, a feedback control is used, enabling the user to attenuate the repeating echoes until they eventually diminish. In order to avoid comb filtering[3] (which can occur with short delay times), a phase switch inverts the phase of the feedback signal. (Izhaki 2008:383)
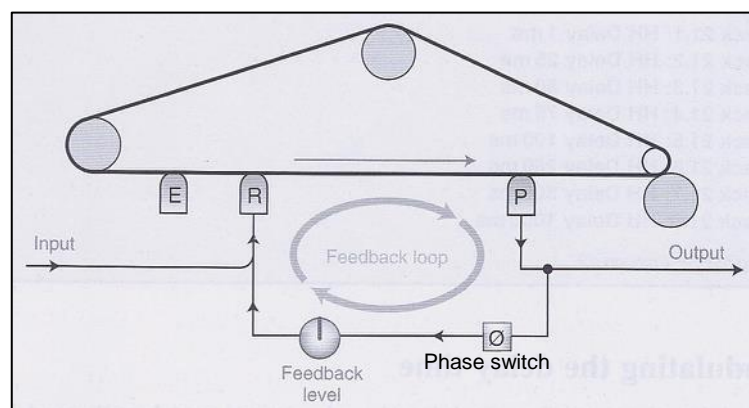
Figure 2. Tape delay with feedback loop (Izhaki 2008:382).

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[3] Comb filters are sets of linearly spaced notches and peaks in the amplitude response (Self 2010:513).

2.2.2 Digital processing delay

The development of digital technology gave rise to digital delay units. Although similar to tape delays, digital delay units differ largely in terms of audio storage. Instead of storing the audio on magnetic tape as is the case with analogue units, their digital counterparts store audio in a digital buffer memory. The operation of this digital buffer is cyclic, similar to the audio tape that is in a loop. The digital unit has record and playback functions in its memory, akin to the respective heads on the tape delay unit. The digital system provides for a very accurate approach to adding delay as an effect; however, the size of the digital buffer memory limits the amount of delay that can be applied (Izhaki 2008: 385).

Digital processing time can cause different recording tracks[4] to become unsynchronised, requiring the application of delay compensation as remedy. Delay compensation is an automated feature available in specific software, such as Pro Tools[5], that can improve mixing and increase recording accuracy. By automatically making adjustments in Pro Tools software to compensate for all latencies that might be caused by inputs, outputs, routing and algorithm processing, [Pro Tools] ensures that recordings remain in time and phase-accurate (Dimercurio n.d.). When a digital processing plug-in[6] is added to an audio track, the computer needs time to process the tracks through the various applied plug-ins, which causes a degree of asynchronism between some tracks. Delay compensation determines which track has the most delay and then automatically delays the other tracks to align with the longest delayed track (Franz 2012).

2.2.3 Transmission delay

Transmission delay occurs due to the rate at which data travels through electronic components, connections and cables. The transmission delay caused by digital hardware can be calculated as follows:

Transmission delay = Data transmission capacity/Data rate,

Thus;

If the capacity of the connection is 100 Kilobytes per second (Kbps) and the data rate is 10 Megabytes per second (Mbps), then:

Transmission delay = 100 Kbps/10 Mbps = 0.1 seconds (Singh 2013)

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[4] A track is an area of memory into which events can be stored (Wilkie 1997:104).
[5] Pro Tools is digital audio software used for recording and production processes.
[6] A plug-in is a piece of software code which enables an application to accomplish a different task (BBC 2012).

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The relatively lower cost of digital processing systems, the accuracy of the delay, as well as the multitude of digital equipment options available, has resulted in the widespread popularity of digital delay units as opposed to their analogue counterparts (Stark 2005:158).

2.2.4 Various causes of delay

A multitude of situations or scenarios can give rise to unwanted delay and latency. In digital technology, for instance, possible reasons for latency can include:

- slow CPU[7] or storage disk drive input/output rate
- monitoring through software processing
- suboptimal input/output drivers
- insufficient digital buffer memory
- wrong buffer technical settings for input/output drives
- improper installation of audio software

In broadcasting, delay can be experienced when multiple cables of different length carry a single signal. This is a common problem experienced in video delivery systems (Self 2010:191).

Latency can also be experienced in acoustic situations where there is a delay between different instruments; for example, in an orchestra setting. According to Bartlette et al. (2006), due to the speed of sound, a double bass player listening to a triangle player on the opposite side of an orchestra can experience latency of up to 80 milliseconds (hereafter ms). Another possible scenario is when a performer hears the sound later than he should due to monitor latency on stage. Although these possible causes for latency will not be addressed in this study, the reader should be mindful that the effect it may have on a musician can be similar to the experiments of this study.

2.2.5 Using delay as an effect

Leonard (1991) established that time-delay can be used for timbral improvement. She found that latency can be used in a recording to increase its perception of depth. Furthermore, the delayed reflections from nearby boundaries provide our brains with information regarding the spatial properties of a room as well as the position of the source from which sound is emitted.

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[7] Central processing unit (Wilkie 1997:23).

In this regard, even the slightest amount of delay can create an impression of depth (Izhaki 2008:393).

Time delay can be used creatively in music to create an "echo" effect. According to Castle Studios (2014), the first creative use of delay was for the purpose of enhancing the quality of radio broadcasts. They did this by reflecting a transmitted signal through a long-distance telephone line. This created a delay of a few milliseconds, which they then added to the radio broadcast. These echoes can also fill empty moments in a recording, thereby adding creative effect. It can also solve stereo imbalance problems created when one instrument is panned to one side of the spectral field, leaving no sound in the opposite side of the field. This can be achieved by sending the instrument through a delay unit, and then panning (spreading) the delayed sound to the opposite side of the spectral field (Izhaki 2008:395).

During the 1950s, the use of analogue magnetic tape was a widespread method of creating delay. Les Paul was one of the leaders of this ground-breaking method of creating delay, and his contribution to the delay effect profoundly influenced the music genre, Rockabilly, which later became widely popular. The "slapback" effect became synonymous with this time period and many notable recording artists employed this technique, as can be heard on the guitar part of Elvis Presley's *That's All Right*[8]. To create this effect, the delay would be set to repeat at a rate of 150 ms to 200 ms (Taylor 2016). Modern digital processing plugins are so advanced that they can emulate the tone of hardware equipment, including guitar processing pedals (White 1998).

When used sparingly, delay can create depth and add warmth to a recording. In modern pop music, it is often used to add brightness and a sense of space. Some engineers even use delay to emphasise a specific lyric. The delay will usually be added to a dry signal (a recording with no effect on). This delay can then be manipulated by the user to create the desired effect. There are various types of delays from which to choose; one such example is ping-pong delay, which generates echoes that move between the left and right channels of the stereo field (Izhaki 2008:390).

While it is nowadays common practice for musicians to use delay in their productions for desired creative effect, this study specifically addresses the way musicians can combat the debilitating factors associated with extreme levels of delay.

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[8] Elvis Presley's version of the song *That's All Right*, originally written and performed by Arthur Crudup, was recorded and released on 19 July 1954 under the label *Sun Records*.

2.3 Audio perception latency

Throughout history, audio delay has been experienced in numerous scenarios. Some of the earliest forms of delay were experienced by musicians in churches, due to the large acoustic spaces within church buildings. Some composers even wrote specific works according to the acoustic properties of specific churches. For example, the 16th-century composer, Giovanni Gabrieli, utilised a sparse compositional style in works such as *In Ecclesiis*, writing in "long-short-short" rhythms to compensate for the spacious acoustic setting of St. Mark's Basilica (Bartlette et al. 2006).

2.3.1 Transfer/propagation latency

Propagation latency is the time it takes for a signal to pass through a cable. The electron-borne signal encounters resistance from the transfer medium. This resistance to propagation induced by the cable is determined by the cable length and material composition.

According to Self (2010:190), propagation delay (in a network setting) is measured in nanoseconds (Dn). The time delay can be converted to the velocity of propagation (V$_p$). Since V$_p$ is directly related to dielectric constant *(DC)*, the delay can be determined as follows:

$$\mathrm{D}n = 100/\mathrm{V}_p, \text{ thus,}$$

$$\mathrm{D}n = \sqrt{DC}.$$

If 1 Dn = 1e − 6 Dm (milliseconds), then:

$$\sqrt{DC} = 1\,\mathrm{e} - 6\,\mathrm{D}m.$$

An electronic transfer cable also imparts an amount of attenuation to the signal. This frequency dependent attenuation *(A)* is expressed as follows:

$$A = 4.35\,(\mathrm{R}_t / \mathrm{Z}_o) + 2.78pf\sqrt{\varepsilon}$$

Where,

A = attenuation in dB

R_t = total direct current line resistance in Ω

ε = dielectric constant of the transmission line insulation

p = power factor of the dielectric medium

f = frequency

Z_o = electrical resistance of the cable (Self 2010:192)

Propagation latency also prevails in certain acoustic settings, where it is manifested by the time of the propagation of sound.

According to the work of Kon and Lago (2004), the percussion and horn sections of a symphonic orchestra are approximately ten metres farther from the audience than the violin section, which can yield a propagation latency of up to 30 ms between the different instrument groups to the audience. Propagation latency (in an acoustic setting) can be calculated by using the following formula:

The speed of sound in air is 340 m/s, then:

Distance in metres/340 = latency, thus,

Propagation latency = 10/340 = 30 ms.

2.3.2 Stimulus response latency

The human neurological functions limit our abilities to react to our perceptions within a short timeframe, resulting in delay. This is a type of delay in which a certain amount of time elapses between the receipt of the signal and the receiver's neurological interpretation thereof. According to Burger (2015), this can be called *reaction time.*

The Human Benchmark Project[9] is an online statistics source which calculates the median reaction time from thousands of participants. It has found that the average human reaction time is approximately 250 ms (see Figure 3). Burger (2015) states that a person's reaction time is directly related to his/her profession. He mentions that fighter pilots, formula one drivers and championship video game players have a reduced reaction time of between 100 ms and 120 ms.

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[9] www.humanbenchmark.com

All - time
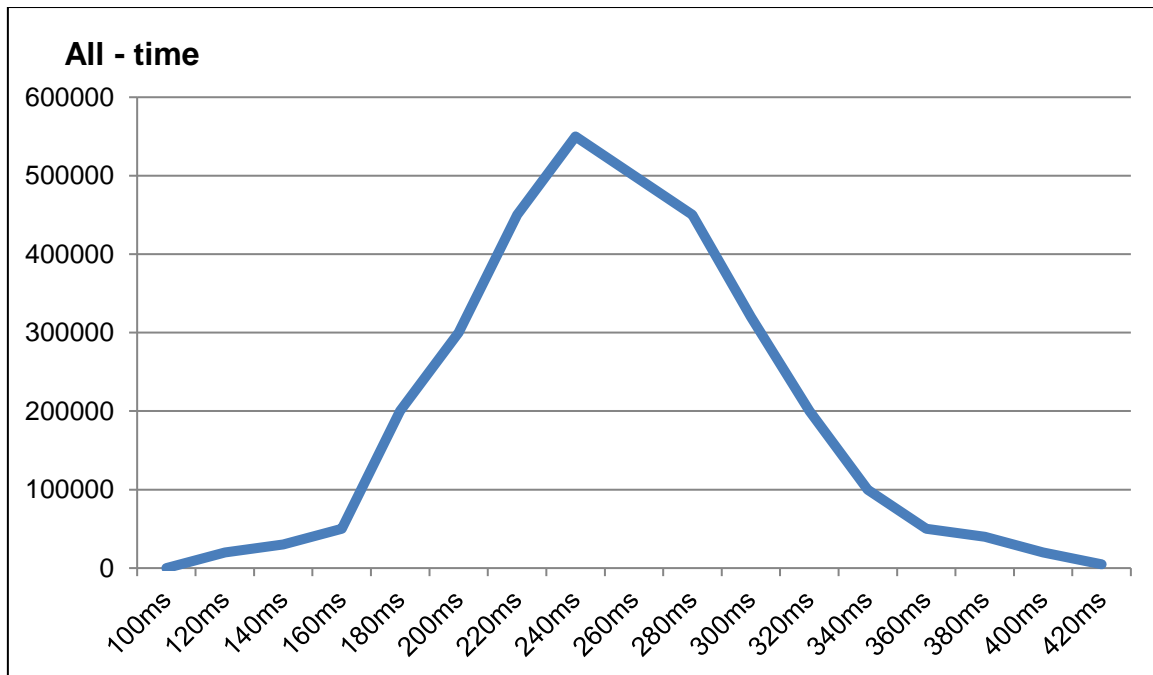
Figure 3. The average human reaction time. X-axis represents the number of milliseconds and Y-axis the number of participants (Human Benchmark 2016).

Burger (2015) also remarks that mental processing consists of four components, including:

- sensory perception
- receipt of input into our consciousness
- context applied to the input
- decision made based on processing output

Sensory perception is the process where our senses receive incoming data (visual or auditory). An asynchronous process follows, where the input is processed and stored in our consciousness. This data is then placed within context in order to make a decision on how to react.

Boley and Lester (2007:2) have conducted research on the tactile feedback experienced by musicians performing with various instruments. They found that saxophonists, for example, require a more immediate feedback than keyboardists, due to the physical attributes of the saxophone. They further determined that tonal instruments are affected more by comb filtering than percussive instruments. For percussionists, the comb filtering creates only a temporal perception issue, whereas for the tonal instruments, it is a problem that affects their overall performance. Based on the auditory feedback, one of the tactile problems investigated by Boley and Lester (2007:3) involved the added difficulty instrumentalists

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experienced in judging when to initiate sound by strumming, hitting and blowing their instruments.

2.4 The sound envelope

The tonal quality of a sound is determined by the spectrum of frequencies contained therein, thus enabling us to distinguish between different sounds. Another influential factor to sound quality is the sound envelope, which is the manner in which the waveform varies in intensity and frequency throughout a sound's duration (Stark 2005:44). Each instrument possesses a specific sound envelope that attributes to its distinctive sound. The specific characteristic parts of sound envelopes are referred to as attack, decay, sustain, and release (see Figure 4). The following terms will hereafter be used in the discussion:

- **Attack time**: The initial period during which the sound reaches its maximum volume after the sound is generated (measured in milliseconds). (Reid 1999)
- **Decay time**: The decline in intensity as the sound level decreases (measured in milliseconds). (Randel 2003)
- **Sustain**: The period of time during which the sound remains constant before it decreases in volume. (Reid 1999)
- **Release**: The time it takes for the sound to decrease to zero. (Reid 1999)
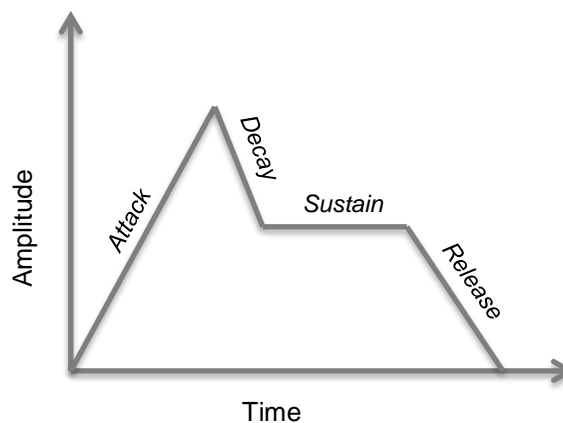
Figure 4. A time-amplitude plot showing the ADSR envelope (Sievers *c.* 2005).

As shown in Figure 5, the sound output of a piano does not immediately reach its full intensity nor does the sound fade away instantaneously (Abraham, Mathew & Scaria 2015*).* The piano sound takes an amount of time to reach its full intensity (attack). The sound level then gradually decreases (decay) until it fades away (release).

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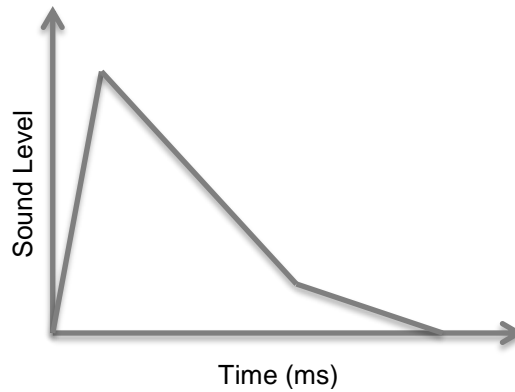
Figure 5. ADSR envelope of the piano (Abraham et al. 2015:23).

The sound envelope of the guitar has an abrupt attack (Figure 6) due to the initial pluck of the strings. The sound has a rapid decay as a result of the fading of nonharmonic frequencies, leaving only the fundamental harmonics.
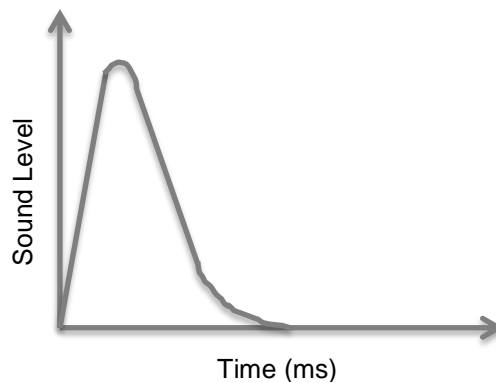
Figure 6. ADSR envelope of the guitar (Chen n.d.).

The sound envelope of the violin (Figure 7) has a slow attack, but a long sustain due to the bowing of the strings, which produces a constant sound. The sound only fades away once the bowing stops, giving an abrupt release (Stark 2005:44).
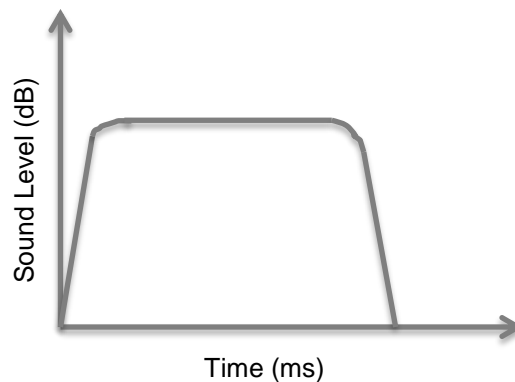
Figure 7. ADSR envelope of the violin (Stark 2005:44).

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The sound envelope of the flute (Figure 8) has a slow attack and a gradual decay. Due to the method of producing the sound, it does not have an observable sustain (Gordeski, Hwang & Sheehan 2004:26).
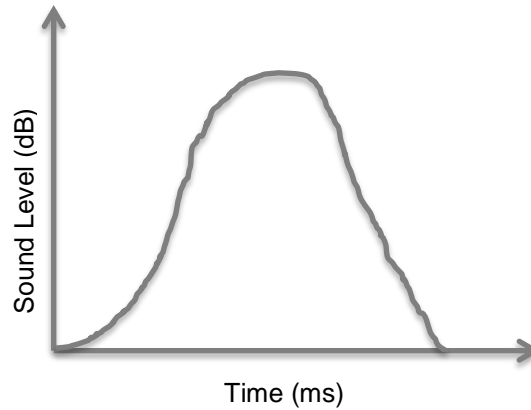
Figure 8. ADSR envelope of the flute (Gordeski et al. 2004:27).

The sound envelope of the snare drum (Figure 9) has a very fast attack with a rapid decay. The sound fades quickly as it has very limited sustain (Stark 2005:44).
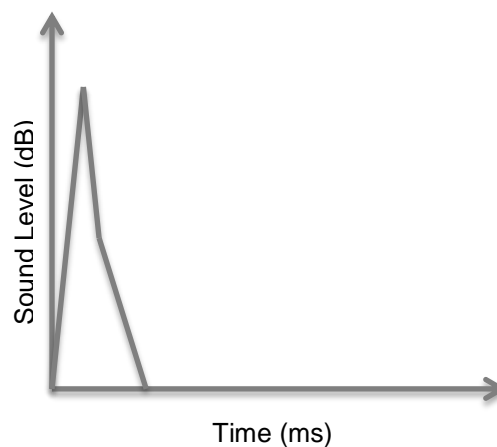
Figure 9. ADSR envelope of the snare drum (Stark 2005:44).

2.5 Previous audio perception studies

Throughout the various relevant literature available, most authors found that musicians can tolerate specific amounts of latency. As soon as this tolerable amount of latency is exceeded, musicians most likely start using various coping mechanisms to compensate for latency until they reach a threshold in which they are unable to perform optimally.

2.5.1 Tolerable latency

Hämäläinen and Mäki-Patola (2004) suggest that tolerable latency is dependent upon the instrument's characteristic dynamic envelope (ADSR envelope), genre of music and presence of tactile feedback (the sensation experienced while touching or playing an instrument). They also anecdotally alluded that some church organs produce latencies of several hundred milliseconds that organists can tolerate (compensate for during performance); this statement was, however, not motivated.

Kon and Lago (2004) further identified three factors that influence a musician's ability to tolerate latency, namely their:

- motor commands (ability to move)
- haptic commands (ability to feel/touch)
- relation to the external feedback (where they are situated in the location and how quickly the prominent audio reflections reach them)

In further research, Boley and Lester (2007) found that acceptable latency can range from 1.4 ms to 42 ms. Through the use of an analogue switchboard that they designed, the latency threshold was tested using a system that users would activate when latency became bothersome. Boley and Lester's study was conducted to aid engineers in determining what criteria to use when designing and employing digital products and systems.

According to Wessel and Wright (2002), latencies of between 7 and 10 ms are acceptable for live performers of computer-based music, whereas greater amounts of latencies can influence the musician's ability to play synchronously. This does not correspond to Barbosa and Cordeiro's (2011) finding of an acceptable 25 to 50 ms latency.

2.5.2 Coping mechanisms

Aschersleben (2001) deduced that, when attempting to participate in time with a metronome, amateur musicians had, on average, a performance reaction latency of 10 ms more than that of professional musicians[10]. She also found that there was an "anticipatory level", where the musicians would tap on the desk before the actual click of the metronome to compensate for

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[10] Aschersleben did not provide a definition for what she perceived an amateur musician to be. For the purposes of this study, an amateur musician will be a musician with little or no formal training in music.

latency. She noted that for keyboard-based performers, an increased amplitude[11] between the finger and the key pressed resulted in reduced asynchrony. Aschersleben concluded that the musicians played with more accuracy when performing with others than with a solitary metronomic aid.

Boley and Lester (2007:17) established that vocalists have a higher general sensitivity to latency, whereas drummers and keyboardists have a low general sensitivity. Keyboardists are accustomed to playing with various settings and many of these settings have a very slow attack time, making them feel as if there is a delay between the finger pressing the key and the resulting sound. Some keyboardists have adapted to this latency and can anticipate the actual attack time.

Arisona, Juillerat and Schubiger-Banz (2007) investigated the effect of latency on real-time audio processing through the use of software-based music production platforms. They found that latencies of less than 20 ms are almost unnoticeable to singers and musicians who perform with melodic instruments, but that musicians using percussion instruments can notice latencies of as low as 4 ms.

In the article, *Effect of time delay on ensemble accuracy* (Chafe et al. 2004)*,* the main findings assert that longer delays produced tempo deceleration, whereas shorter delays produced acceleration. It was found that rhythmic accuracy deteriorated significantly as the delay increased. The authors' findings suggest that musicians adapt the tempo of the performance in order to compensate for latency they experience.

During an investigation by Carôt, Krämer and Schuller (2006) into the effects of latency on networked music performance, it was found that jazz musicians are able to compensate for latency due to the free timing the music genre requires. However, musicians who play other genres that require a perfectly timed performance are posed with a bigger problem when confronted with latency.

2.5.3 Threshold

Burger (2015) established that the fastest rate at which humans are able to process stimuli is 13 ms. He noted that a faster rate will go by unnoticed, whereas a rate slower than 13 ms will

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[11] The term "amplitude" refers to the distance between the finger and the key pressed.

negatively impact human performance for a given task. He found that, dependent upon the individual and task at hand, an increased latency will degrade a person's processing ability, although latency is tolerable up to an approximate 75 ms to 100 ms. He elaborated that between this range, one will become increasingly aware of the input of stimuli becoming too slow and adapt the conditions by anticipating input instead of merely reacting to it.

Boley and Lester (2007:17) found that a delay of less than 11.5 ms caused 75 per cent of their participants to speed up their performance, whereas a delay of more than 11.5 ms caused 85 per cent of the participants to slow down.

Bartlette et al. (2006) investigated the effects of different amounts of delay on coordination, pace and timing regularity of musicians by placing them in remote locations. They placed two pianists in separate rooms, connecting them via microphones and headphones. Different levels of latency were then introduced, ranging between 0 ms and 200 ms. It was found that the performance coherence deteriorated quite significantly beyond the 100 ms delay mark. The musicians mentioned that at these latency levels, they attempted to ignore each other in order to maintain a self-coherent performance.

Perception latency in group performance has been found to affect the quality of musicians' musical performance. Barbosa and Cordeiro (2011) conducted an empirical study on music ensembles and defined the maximum tolerable temporal latency for coherent music performance participation as "ensemble performance threshold" (EPT). This study established the EPT for successful musical performance collaboration to be 40 ms. An increase in latency beyond 40 ms resulted in asynchronous playing and eventually it became intolerable for the musicians to play. Barbosa and Cordeiro further found that tempo, dynamics, articulation and competency levels were factors which influenced the amount of latency that could be tolerated by the musicians and enabled an effective EPT finding for each performance.

A comparison between previous latency studies (Barbosa & Cordeiro 2011; Wessel & Wright 2002) points to inconclusive and opposing viewpoints, indicating a need for further investigation; hence the purpose of this study.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

The research methodology is the general approach the researcher has taken in order to carry out the research project (Leedy & Ormrod 2001:12). This chapter will discuss the approach and design of the study, as well as the data collection methods and a brief description of the analysis method to be utilised.

3.2 Research approach

According to Bryman (2012:46), qualitative research focuses on words rather than the quantification in the collection and analysis of data. Mouton (2001:107) notes that qualitative researchers use field notes as they participate in fieldwork. These notes can be useful during the semi-structured interview process where observations are made during the participants' practical experiments. According to Leedy and Ormrod (2001:12), qualitative research is used to describe a phenomenon from the participants' point of view. Since focus is placed on the participants' own experiences during the data collection process, the research is conducted with a qualitative approach.

3.3 Research design

The study is conducted through participatory/action research, combined with participatory/observation research (Mouton 2001:50-55). According to Mouton (2001:150-151), participatory/action research involves the subjects' active participation as an integral part of the research process. Subject participation is vital to the current study in order to understand the effect of latency upon the participants. Hofstee (2006:127) specifies that participant observation, as an ethnographic research method, observes a particular group to gain an understanding of that group. He further remarks that ethnographers use both observations and interviews in their work. This applies to this study, as the researcher uses observations made during both the data collection process and interviews to gain an understanding of the influence of latency on the participants.

A laboratory delay study is utilised to test and compare the effect of latency on different musicians' performance ability. The sound is processed by means of audio delay software, the output of which the musician (participant) hears through a set of isolated audio headphones. The musician commences by performing the self-selected musical piece with

no audio latency processing, after which the duration of the induced latency is increased in increments of 5 to 20 ms. This process is sequentially repeated until the musician finds it intolerable to perform. The results of these experiments are compared with the conducted literature study to obtain an overview of the existing research corpus on related topics. To circumvent in-process learning, each participant is permitted to execute the experiment only once.

3.4 Sampling strategy

Participants are selected according to different instruments, competency levels and studio experience. Musicians who play various instruments are evaluated to deduce the effect of tactile feedback and their ability to address auditory latency. Musicians of various levels of expertise are evaluated to ascertain whether or not experienced musicians are able to tolerate higher levels of latency. Musicians with different levels of studio experience are tested to understand the effect of pre-exposed studio techniques on the coping strategy of the musician.

Ten participants are selected to conduct the experimental part of the study. These participants are given the choice between performing either a rehearsed or improvised piece. Since the researcher's intention is to only investigate the effect of latency on the musicians, they are required to perform individually in order to negate any variables that could be experienced while performing within a group setting. The participants are all from the Gauteng area for the purposes of accessibility to the recording studio (laboratory) at which the experiment is conducted.

3.5 Ethical considerations

According to Hofstee (2006:118), this type of study has certain ethical implications which need to be addressed. Since this study makes use of participants, their consent is required. The consent form (Appendix A) informs them of the objective and procedures of the experiment, as well as that they are partaking in the experiment on a voluntary basis and are free to withdraw at any point without prejudice. Participants are also made aware that the interviews will be recorded.

To keep the participants' identities confidential, numerical pseudonyms (P1 to P10) are assigned to the participants. The identities of the participants are known only by the researcher and their names shall not be used or revealed.

To provide valid and reliable information, the same procedures and assessments are applied for all the participants. To further ensure validity and reliability, interviewing schedules and observations are used as measuring instruments for data collection (Mouton 2001:100).

3.6 Coding

The researcher has employed the coding process utilised by Saldaña (2009) for this study. In qualitative inquiry, a code is a word or a short phrase that assigns a summative description to a portion of data. A coding system is utilised for data analysis as it provides a systematic approach to organising and evaluating the data on hand. These codes are applied to the researcher's transcripts and field notes in order to find the essence and commonalities between participants' observations, and are subsequently analysed to address the research questions.

To accurately utilise the coding system, the researcher will look for repetitive or consistent data that appears throughout the experimental process. This data can be words (codes) that are similar/different, used frequently or in sequence, or words that correspond to one another.

For the purposes of this study, structural coding will be used. It is a coding process applicable to studies that use interview transcripts from multiple participants and a semi-structured data-gathering method. This is a question-based process that categorises the data corpus according to commonalities and differences (Saldaña 2009:98). Structural coding identifies large segments of text that will form the basis for analysis and discussion, and provides a content-based or conceptual phrase to a segment of data that relates to a specific research question. Segments that are similarly coded are then discussed and analysed. Recommended ways to analyse the structural codes are by means of content analysis and the utilisation of illustrative charts and diagrams.

CHAPTER 4: RESULTS

4.1 Introduction

This research employs the structural coding method of grouping the participant's various experiences according to the specific research questions. According to Saldaña (2009:98), structural coding categorises data according to commonalities, which in this case will be the research questions. Semi-structured interviews are used for data collection. These interviews are recorded, transcribed (Appendix C) and used to present the views and responses of each participant to the posed research questions. Segments of data are preceded by the particular research question, followed by its related structural code, which is numbered in antecedent superscript. These structural codes are in turn linked to the Discussion in Chapter 5. In this chapter, the data is grouped and analysed according to the research questions. Tables are utilised to showcase the answers to the final research question, which include the amount of latency that the participants felt were the limit for optimal performance. The outcomes of the results are reviewed in Chapter 5.

4.2 Structural codes

Upon data review, the structural codes are found to be the following:

1. Coping mechanisms to compensate for latency
2. Manners in which performances are affected
3. Influence of music training on performance ability
4. Metronomic assistance
5. Latency threshold

An explanation follows as to how the structural code has come about, as well as the reason for its association with the respective research question. Where appropriate, excerpts from the transcripts of the participants have been used to validate the choice of code:

Research question 1: Can the debilitating effect of perception latency be compensated for during online music collaboration?

Structural Code: [1]Coping mechanisms to compensate for latency

Research question 1 investigates the different types of coping mechanisms used by the participants to aid them in their performance. The commonalities between the participants' answers are the various coping methods used during their performances, hence the structural code. The responses from Participants 1, 2 and 7 are some of the examples of the coping mechanisms utilised:

> P1: *…it feels like, uhm, you have to start playing faster to compensate for that and what basically happens is you're starting to rush and you get off-click actually without noticing.*

> P2: *…it became increasingly difficult to play in time and I found myself having to use bodily movements, like nodding my head, to try and keep time.*

> P7: *I tried to sing louder…*

Research question 2: To what extent will latency influence the musician's ability to perform optimally?

> **Structural Code:** [2]Manners in which performances are affected

Research question 2 examines the different ways in which the participants' performances are affected. The commonalities between the participants' answers are the various ways participants need to change or adapt their performances. The responses from Participants 5, 6 and 8 are some of the examples of how their performances were altered:

> P5: *It slowed my playing…*

> P6: *…I had to focus more on keeping in time…*

> P8: *…sometimes I'd try play something and then obviously I wouldn't hear it, so my fingers would try play it again…*

Research question 3: Does the extent of the musician's music training influence his/her ability to compensate successfully for perception latency?

> **Structural Code:** [3]Influence of music training on performance ability

Research question 3 explores the influence, if any, of formal music training on the participants' performances. The commonalities between the participants' answers are the various ways in which formal music training affects performances, if at all.

Research question 4: To what extent can metronomic aids assist a musician to compensate for communication and processing-induced perception latency?

Structural Code: [4]Metronomic assistance

Research question 4 investigates the effect of a metronome as an aid to participants' performances. The commonalities between the participants' answers are the influences of the metronome on performances. The responses from Participants 2, 3 and 5 are some of the examples of how the metronome assisted in their performances:

P2: *The metronome made it much easier. Uhm, I could switch off the music in my head and try to listen exclusively only to the metronome, which made it easier to perform.*

P3: …*the click really helped with the latency in that sense.*

P5: …*it did help me to stay in the correct rhythm.*

Research question 5: What is the maximum amount of latency that musicians can tolerate and how will this affect them when utilising latency-inducing technologies such as in-line audio processing?

Structural Code: [5]Latency threshold

Research question 5 investigates the maximum amount of latency that musicians can tolerate. Table 1 below displays the maximum amount of latency that the participants were able to tolerate during their performance. The participants' attempts with and without the metronome is shown in the table. One of the vocalists performed to a backtrack accompaniment, which took the role of a metronome.

Table 1. Maximum amount of perception latency that participants can tolerate.

Participant	With metronome	Without metronome	With accompaniment	Without accompaniment
P1	80 ms	200 ms	-	-
P2	40 ms	40 ms	-	-
P3	25 ms	50 ms	-	-
P4	50 ms	70 ms	-	-
P5	30 ms	50 ms	-	-
P6	100 ms	100 ms	-	-
P7	-	-	400 ms	100 ms
P8	225 ms	160 ms	-	-
P9	100 ms	40 ms	-	-
P10	35 ms	40 ms	-	-

The different amounts of latency thresholds for participants with formal training, as well as those with no training, are presented in Table 2 (with metronomic aid) and Table 3 (without metronomic aid).

Table 2. Participant perception latency threshold when performing with a pre-recorded metronomic aid.

Participant	Formal training	No training
P1	80 ms	-
P2	40 ms	-
P3	25 ms	-
P4	50 ms	-
P5	-	30 ms
P6	100 ms	-
P7	-	400 ms
P8	-	225 ms
P9	100 ms	-
P10	35 ms	-

Table 3. Participant perception latency threshold when performing without a pre-recorded metronomic aid.

Participant	Formal training	No training
P1	200 ms	-
P2	40 ms	-
P3	50 ms	-
P4	70 ms	-
P5	-	50 ms
P6	100 ms	-
P7	-	100 ms
P8	-	160 ms
P9	40 ms	-
P10	40 ms	-

4.3 Summary

This chapter has shown the results deduced from the data through the reflection of the threshold values of perception latency in Tables 1 to 3. The reasoning behind the use of the structural codes was also explained, each of which will be expounded upon in the following chapter.

CHAPTER 5: DISCUSSION

5.1 Introduction

In this chapter, the outcomes of the results are discussed and interpreted. The order of discussion is consistent with the order of the research questions, which are addressed in accordance with the specific structural code. At specific places, figures have been used to visually represent the outcomes of a particular research question in order to give a clearer indication of the effect on the various participants.

5.2 Interpretation of results

The structural codes indicated in this chapter are linked to their corresponding codes specified in Chapter 4.

5.2.1   [1]Coping mechanisms to compensate for latency

The results indicate that participants employed various coping mechanisms in order to compensate for latency. Figure 10 shows that 80 per cent of participants changed their focus in some way or another. Both the changing of tempo and the use of kinesthetic movements, such as tapping the leg or nodding the head, were recorded at 70 per cent respectively. Only 40 per cent of the participants modified their performance dynamics; for example, the vocalists sang louder in an attempt to drown out the delay.
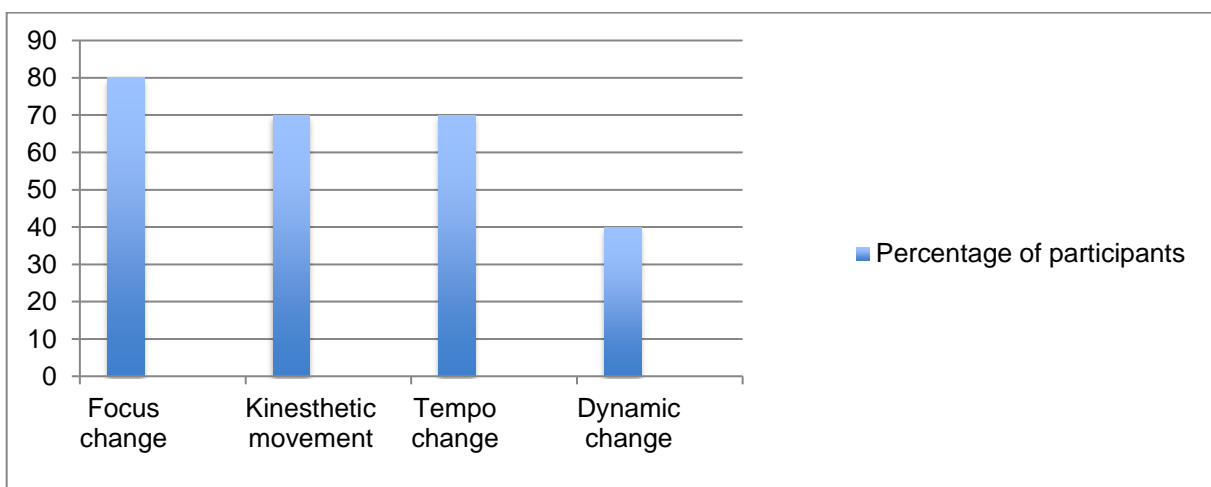

Figure 10. Percentage of participants that utilised a specific type of coping mechanism to compensate for audio perception latency.

5.2.1.1 Changing focus

Essentially, all of the participants aimed at concentrating more on their playing than on the sound that they heard back through the headphones. Participant 1 mentioned that he focused on the sound resonating from the guitar itself, rather than that of the headphones. Participant 2 expressed that she discarded musicality and focused only on the beat to give her an indication of where to fall in. Similarly, Participant 8 mentioned that she had resorted to playing in a very mechanical, robot-like fashion in order to remain on the beat. Participant 3 stated that he was driven to change his style of performance, as latency caused him to lose the "feel" of the music. Participant 4 noticed that her focus was more on the movement of her hand to try to compensate for latency.

As latency increased, Participant 6 specified that she had to concentrate more on her actual performance than on latency. Participant 7 mentioned that she needed to focus more on her pitching than she usually does during a performance. Participant 8 noticed that she played certain notes two or three times, as latency made it sound as if she had not played those notes. She further mentioned her attempts at relying solely on muscle-memory and ignoring the sound she was hearing through the headphones, which she said had caused her performance to become very mechanical and devoid of any emotion. This finding correlates with that of Boley and Lester's (2007) in that instrumentalists find it difficult to judge when to initiate sound. Participant 9 noticed that the increased latency required him to rigorously concentrate on the metronome to keep in time with the music. Participant 10 noted that, in order to compensate for latency, she focused on accenting the strong beats of the music.

5.2.1.2 Kinesthetic movement

Some participants employed a form of physical movement to aid them with their performance. This correlates with Kon and Lago's (2004) finding that motoric movements are one of the factors that influence a musicians' ability to tolerate latency.

Participant 2 noticed that she started to nod her head to maintain a steady beat. It was observed that Participants 2, 3, 9 and 10 started to tap their feet to try and compensate for latency. Participant 5 began to tap her foot to keep in time with the music. Both Participants 6 and 7 started to tap their legs to compensate for latency.

5.2.1.3 Changing tempo

The results indicate that the effect of perception latency can be balanced out by changing the tempo at which the participants performed, as this allowed them to catch up to the tempo of the song if latency affected their timing. While it is true that this affected the quality of the performance, the participants were still able to continue with their performance if they increased or decreased their tempo when their timing was affected. This finding correlates with that of Chafe et al. (2004) in that musicians will adapt the tempo of performances when confronted with latency.

Both Participants 1 and 4 changed the tempo of their performances to compensate for latency. As latency increased, they noticed that they were playing slower which made them abruptly increase their tempo to get in time with the music. Participant 3 noticed that he needed to shorten the last notes of every bar, so that the delayed sound would not affect the next note to be played. Participant 5 decreased the tempo of her performance as she tried to compensate for latency. The timing of participant 6 became increasingly unsynchronised with the music. Participant 9 increased the tempo of his performance. Participant 10 compensated for latency by bowing somewhat faster in order to more accentuate the strong beats.

5.2.1.4 Changing dynamics

To compensate for latency, all the vocal participants began to sing louder to drown out the delayed sound. This compensation method was more successful for some than others, allowing some to continue with a reasonably successful performance. However, Participant 6 started to sing forcefully loud, which decreased the quality of nuances in her performance.

5.2.2 [2]Manners in which performances are affected

As latency increased, most participants started to play out of time. Their tempos were either rushed or slowed down. Participant 1 began to play faster to keep up with the music, while participant 2 decreased the tempo of her performance. Participants 3, 4, and 5 alternated between an increase and decrease in performance tempo. Participants 6 and 7 even changed the audio level at which they sang to drown out the sound that they heard back through the headphones. The performance accuracy of Participant 8 was influenced to such a degree that she repeated notes, thinking that she had not yet played them because of the delayed sound that was heard. Participant 9 started to rush ahead of the metronome, which

correlates with Burger's (2015) finding that musicians will anticipate the input by playing ahead of the metronome.

The majority of the participants also commented that they resorted to relying more on muscle-memory than on the sound that they heard, which in turn created very mechanical performances devoid of individual musical interpretation.

5.2.3 [3]Influence of music training on performance ability

By observing the maximum amounts of latency that the participants could tolerate, it appears that a musician's music training does not necessarily affect their ability to compensate for latency. As seen in Tables 2 and 3, the maximum limit for participants varied significantly and it would seem that a musician's previous experience with metronomic aids could have a bigger influence on their ability to compensate for latency than formal music training.

It seems that the proficiency level of a musician does not necessarily support their ability to perform when confronted with latency. This implies that frequent past exposure to latency, rather than formal music training, is a better precursor to the ability to cope with latency.

5.2.4 [4]Metronomic assistance

While the metronome was helpful to some participants, it proved a hindrance to others. Three participants could tolerate a higher latency when they performed with the metronome, while five participants found it better to perform without the metronome. As seen later in Figure 12, only two participants' outcomes seemed unaffected by the metronome.

For Participants 1, 4 and 10, performing with the metronome was more of a hindrance than an aid. While Participant 1 had previously been exposed to playing with a metronome, this experience did not necessarily help him with his performance. He noted that he was more conscientious of playing in exact time with the metronome, whereas when playing without it, he could deviate slightly from playing in time and still accurately perform. He further noted that the metronome made him very aware of his timing and thus realised that there is significantly more room for error when playing with a metronome. Participant 4 mentioned that she completely ignored the metronome and that it became a mere irritation. It was observed that this participant experienced difficulty in playing with the metronome from the onset of the experiment, possibly owing to the fact that she had never before played with metronomic aids. Even with experience in playing with a metronome, Participant 10 found it

to be a distraction and preferred to play without it. It would thus appear that her experience with the metronome also did not assist in her performance.

Participants 2, 3, 5, 6, 7 and 9 all found it easier to perform with the help of a metronomic aid. Participant 2 commented that she focused solely on the metronome and attempted to listen past the music. Through the review of the waveform of the recording (Figure 11), it was also noted that this participant ended on time while playing with the metronome. This is an interesting find because this participant had never before recorded with a metronome.
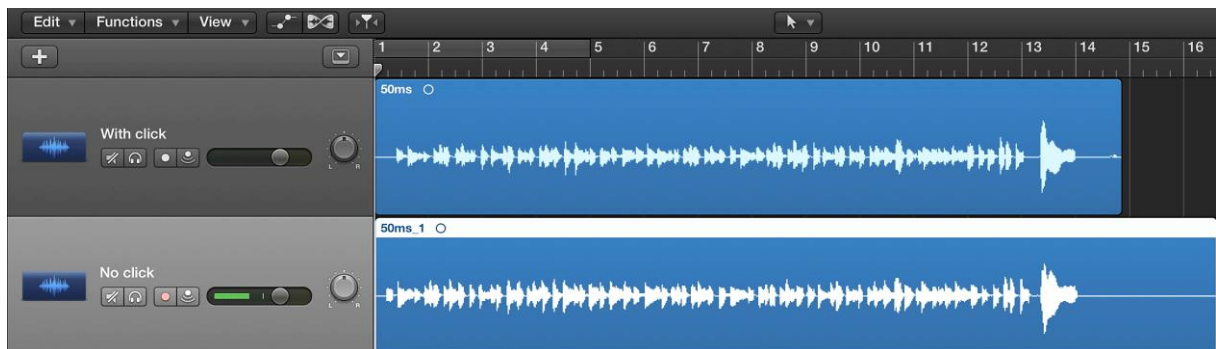

Figure 11. Recorded waveform of participant 2. The top track is the recording with metronomic aid and the bottom track without metronomic aid.

Participant 3 mentioned that at a certain point he ignored the music and looked at his hand while performing with the metronome. This participant has had previous experience with the metronome and therefore it was not a new sensation for him to perform with it. Participant 5 noted that the metronome helped her to stay on time, even though she had never performed with a metronome before. Having had previous experience in performing with metronomic assistance, participant 6 also found it helpful to perform with it. For participant 7, who likewise had had previous experience with metronomic aid, the metronome helped her to sing in time (as observed in Figure 12). Another participant with previous metronomic experience is participant 9, who commented that performing with a metronome gave him a clear guide to follow when latency became too much.

Participant 8 experienced a mixed reaction to playing with the metronome. The researcher noticed the participant's performance became far more consistent when playing with the metronome, but the participant felt it confused her as she tried to listen to the metronome while the delay drowned out the actual timing of the performance. Her reaction might also owe to her never having had played with a metronome prior to the experiment.

It would seem that performing with a metronome positively affects performances when the musicians are faced with a performance hindrance such as latency. It helped the majority of the participants in having a consistent performance, and served as a guide that they could use to follow. This correlates with Aschersleben's (2001) finding that a metronomic aid will assist a musician when confronted with latency-induced performances. Only a small number of participants found the metronome to be a hindrance. In a band performance scenario, the drummer would act as the metronome, thus providing a focus point and guide to other band members when exposed to latency during a live performance.

5.2.5 [5]Latency threshold

The maximum amount of latency that the participants could tolerate is noticeably varied. 60 per cent of the participants reached their limit at the 40 ms to 60 ms range, while the other 40 per cent went well over the 80 ms range. This finding coincides with the research of Barbosa and Cordeiro (2011), as well as Boley and Lester (2007), as they also established the 40 ms range to be the threshold for an optimal performance. This also explains Kon and Lago's (2004) findings that a propagation latency of 30 ms will be unnoticeable to the audience, since this latency amount is still tolerable.
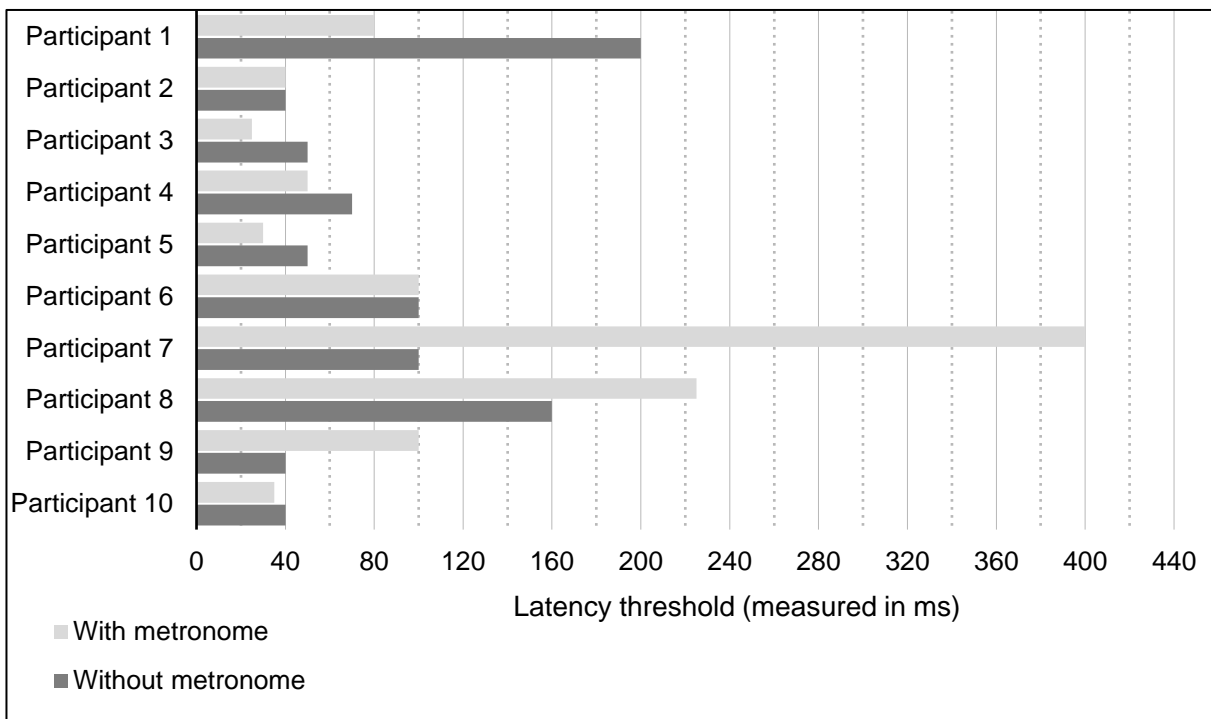

Figure 12. Maximum amount of latency participants could tolerate with and without a metronomic aid.

The participants that managed to exceed the 200 ms mark did so by disregarding musicality and, effectively, musicianship. Participant 7 increased the audio level at which she sang and she disregarded dynamics to drown out latency. Participant 8 mentioned that her performance purely became a mechanical one and that she relied solely on muscle-memory. Both these scenarios were not conducive to an optimal music performance, which implies that a substandard performance will be experienced when performing in this latency range.

Boley and Lester (2007) also found 42 ms to be the threshold for their participants during their experiments. However, Leonard (1991) found the threshold to be 10 ms. This is most likely because he did not see this threshold as the actual limit at which the musician could perform, but focused more on the ambience that latency created.

5.3 Summary

In this chapter, the results were discussed according to the structural codes and the data reviewed in relation to the research questions, which will be clearly answered in the following chapter.

CHAPTER 6: CONCLUSION

6.1 Introduction

The purpose of this study is to ascertain the maximum amount of latency that musicians can tolerate and whether or not musicians can employ coping strategies to compensate for perception latency. The structural coding method has been utilised to analyse the data in order to answer the research questions.

6.2 Answering the research questions

Can the debilitating effect of perception latency be compensated for during online music collaboration?

The results indicate that perception latency can be compensated for through the utilisation of various techniques, such as increasing/decreasing the tempo, adjusting the audio level of one's playing, focusing more on the metronome/beat and using kinesthetic movements to keep playing in time. These techniques were reasonably successful for some participants, while for others the quality of musical performance deteriorated.

To what extent will latency influence the musician's ability to perform optimally?

It was found that latency varyingly affects musicians when in latency-induced performance scenarios. Some musicians used kinesthetic movements, such as tapping their foot or nodding their head, to compensate for latency. Other musicians adapted (increased and/or decreased) the tempo of their performance. All of the vocalists increased the audio level of their performance, which is not conducive to an optimal performance.

Does the extent of the musician's music training influence his/her ability to compensate successfully for perception latency?

The results indicate that a musician's formal music training does not aid them in coping with higher amounts of latency. Some of the participants that have had extensive music training found the metronome to be a hindrance. This can be related to these participants deeming musicality and personal interpretation an important aspect of a performance. When therefore confronted with a rigid method of keeping time while having to concentrate on extreme

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latencies, these participants found the situation intolerable and could no longer perform. This is a good indication that musicians' personal approach to performance and ability to put emotion into their performance influences their capacity to tolerate performance hindrances such as extreme amounts of latencies.

To what extent can metronomic aids assist a musician to compensate for communication and processing-induced perception latency?

It appears that previous studio experience or exposure to metronomic-aided recording methods impacts the amount of latency that musicians can tolerate. Vocalists are more effectively capable of tolerating stimulus response latencies because they are better able to hear the undelayed sound that they produce, whereas guitarists and pianists are more affected by latencies due to the tactile feedback that their instruments require. For the most part, the participants that played instruments resorted to ignoring the sound they heard through the system and relying on muscle-memory in order to continue their performance.

What is the maximum amount of latency that musicians can tolerate and how will this affect them when utilising latency-inducing technologies such as in-line audio processing?

The amount of latency that musicians can tolerate is influenced by various factors that have been addressed within this study. However, participants found the maximum amount of tolerable latency to be in the 40 ms to 60 ms range. Higher amounts of latency gave rise to unwanted performance hindrances.

6.3 Recommendations for further study

The participants in this study were tested in a studio environment with a laboratory-simulated delay. Further study could explore how musicians compensate for latency on an actual stage during a live performance and if the same methods are used as was found in this study. Since the musicians in this experiment were at liberty to stop the performance at any point where latency reached an intolerable level, one could thus safely assume that they may well have been more comfortable in the studio than they would be on stage in front of an audience. This begs the question of how musicians would react to intolerable latency when performing on stage. One could research into whether or not the mere pressure of the proverbial "show must go on" would influence the amount of latency that could be tolerated,

and more broadly, whether emotional stress plays a legitimate role in the ability to cope with latency during a live performance.

In the laboratory-simulated delay scenario, musicians were placed alone and were required to perform over their own delayed signals. Further research can be conducted into the effects of latency issues faced in a band or ensemble scenario and whether the group dynamic assists in combatting such issues. Certain coping mechanisms could enable musicians to still perform while exposed to latency, such as in the case of a contemporary band where the drum kit on stage is prominently loud, thus assuming the role of a metronome. Another coping mechanism may be the visual advantage of seeing the other musicians, thus being able to collaboratively follow one another.

Although not falling within the scope of this particular study, of value will be an investigation into the effect of the level of prior frequent exposure to latency on the ability to tolerate latency more effectively. Lastly, the effect of latency on performers across different music genres and styles could also be investigated.

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APPENDIX A: CONSENT FORM

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Title of the study: The influence of perception latency on the quality of musical performance during a simulated delay scenario.

Purpose of the study: One of the problems musicians face when collaborating online is internet transfer latency. A laboratory simulation delay study will test the effect of latency on musical performance. The musician will be subjected to various levels of latency.

Procedure: Participants will start by performing with no delay, after which the amount of latency will gradually increase with increments of 5 ms until it may become intolerable for the participant to perform. The participant will then be asked to complete a semi-structured interview. This interview will be recorded for transcription purposes and analysis.

Risks and discomforts: The experiment is relatively low-risk and the average musician should not experience any discomfort while participating. Participation is voluntary and participants may withdraw from participation in the study at any time, without any negative consequences.

Confidentiality: All information is treated as confidential. Participants can be assured that their identities will not be revealed in any research outputs. Should the participant elect to withdraw, the data would be destroyed. All data will be kept in secure storage at the University of Pretoria for a period of 15 years. By signing this consent form, the participant acknowledges that the data may be re-used for further research and other academic purposes.

_____   _____
Researcher   Participant

Date:

APPENDIX B: SEMI-STRUCTURED INTERVIEW SCHEDULE

1. Please state the extent of your formal music training (if any).

2. What instrument do you play?

3. Did you rehearse for the experiment or did you improvise?

4. How did an increase in latency affect your playing capability?

5. Did you find yourself having to compensate for latency? If so, please explain.

6. In what ways did playing with a metronome influence your ability to perform with increasing latency?

7. Did you have to change your usual approach to performing as latency increased? If so, please explain.

8. Have you ever recorded in a studio before? If yes, have you been exposed to click-track recording methods?

APPENDIX C: INTERVIEW TRANSCRIPTS

The interview questions are followed by the participants' (P) responses. The observer's comments (OC) have been added to provide additional expository detail of individual participants' experiences.

Researcher: Did you find yourself having to compensate for latency?

P1: Yeah, basically when you start dragging, it feels like, uhm, you have to start playing faster to compensate for that and what basically happens is you're starting to rush and you get off-click actually without noticing.

P2: Uhm, definitely. Especially without the ticks, uhm, it became increasingly difficult to play in time and I found myself having to use bodily movements, like nodding my head, to try and keep time.

OC: *Participant started tapping her foot at about 25 ms to compensate for latency. At 50 ms, she also started nodding her head.*

P3: I did. Uhm, it also changed the feel and I needed to concentrate on the feel I was trying to lay down and then I couldn't really get to that point, but, uhm, it did influence my feel and I tried to compensate for that, yeah.

OC: *Participant started to nod his head to compensate for latency.*

P4: Yeah, I kept trying to play faster to catch up with the sound and other times it would make me want to play slower, then I realized I'm playing slower and then I'd try to pick it up again.

P5: Yes, at times I had to tap my feet to concentrate on the rhythm of my strumming.

OC: *Participant started to play slower to compensate for latency.*

P6: Yes, definitely, uhm, I had to compensate. Well, with the click-track—when you added the click-track, I definitely stopped to hear the click-track and make the notes shorter and that's how I compensated; uhm, as well as I focused on my breathing more on my technical aspect of singing because I was frustrated and couldn't hear myself properly.

OC: At 35 ms, the participant started to sing louder to compensate for latency. Her timing was heavily influenced at 100 ms. At 200 ms, she was forcing the notes and singing extremely loud.
The participant was tapping her leg to keep time.

P7: I tried to sing louder and put effort and emotion into singing as the delays was [sic] drowning my own vocal.

OC: Participant started singing louder. She also started to tap her leg to keep in time.

P8: Yes, exactly, by doing things like that, by playing notes two or three times, by trying to separate the sound from what I was physically doing and just trying to rely on muscle-memory, but it's difficult 'cause obviously as a musician you're taught to rely on your ear, that's an essential part. So it's difficult, and there's a little discrepancy happening.

P9: Yes, I noticed that I had to start tap [sic] my foot to keep in time with what I was playing.

OC: Participant is playing faster (and other places slower) and tapping his foot to compensate for latency.

P10: I feel that I had to tap my foot and concentrate more to stay on the beat and in time.

OC: I noticed that she started to tap her foot to compensate for latency.

Researcher: Did you have to change your usual approach to performing as latency increased?

P1: Yes. I basically had to focus on different sources of the sound, like I had to focus on the sound generating from my guitar itself rather than the sound coming through the monitors or headphones.

P2: I think the biggest change, uhm, was having to discard musicality and listen exclusively to the beat and where I have to fall in and where I have to play, so I think it would be very unmusical performances if performed in this way.

P3: Yeah. All the pickups of the last, say, count of every bar, I had to sort of rush to get into the next bar because I was playing later. Well, I thought I was playing later, I think. So, I'm trying to get my head around that, but at the end of every bar, I felt like I was losing time because of the latency dragging and then pushing back into timing. It felt like at the end of each bar I tried to make up for what I lost.

P4: Yeah, uhm, you know, normally if you play, you hear exactly what you're playing at the right time and you hear your voice and you just go on, but now it's like I tried to focus more on what my hand was doing because what I was hearing was confusing me.

P5: Yes, I changed the tempo of the song.

P6: Uh, yes, I was more focused actually on singing correctly as it increased to make sure [sic] that, and obviously I was singing louder.

OC: *The participant started singing forcefully loud to compensate for the delay.*

P7: Yes, I had to keep the rhythm with my hand and concentrated more to pitch 'cause [sic] it did not feel as if I could—was singing correctly.

P8: Well, yeah, again by separating, uhm, from what you would usually get really involved in and get emotional with or try add something to the piece, uhm, you have to try make it very mechanical and separated, because it's not matching up and it's very confusing and terrible, really.

P9: Yes, I had to tap my foot and also had to concentrate more on the click instead of the sound.

P10: Yes. Yeah, so concentrating more, maybe moving the bow a little bit faster and I also played more on the beat, so I tried to listen for the strong beat and accented that more than usual.

Researcher: How did an increase in latency affect your playing capability?

P1: Well, it basically keeps sounding like you're dragging. Even though you might still be on time, you compensate by keep playing faster.

P2: Uhm, in the beginning stages it didn't make much of a difference, but the longer the latency was, the more difficult it became.

OC: *Participant started to play out of time and at 50 ms she was playing extremely slow.*

P3: Uhm, the latency made me feel uncomfortable in a sense of, uhm, trying to compensate for it, uh. It made me feel—as further we went through this whole experiment, it felt like I was trying to keep up with the pick—uh, the click and with myself where there was no click, so I had to—uh, it felt like I should play faster because I'm hearing myself later, so I'm trying to compensate for that later versus faster.

P4: It irritated me. I tried to, uhm, stick to—because I know the song, so I tried to stick to what I knew about the song to just go into auto-pilot, but sometimes it was difficult because then I would start listening to what I was actually hearing instead on focusing on what I was actually playing.

OC: *Participant started playing slower which affected her timing.*

P5: It slowed my playing and singing every time that it increased the delay.

OC: *Participant started to play slower to compensate for latency. I noticed her timing is heavily affected by the delay.*

P6: Uhm, in a lot of aspects it—pitch-wise, it was very much similar. I didn't have trouble with pitch, but I definitely had trouble with timing, uhm, and I had to focus more on keeping in time.

OC: *The participant was starting to sing forcefully loud. Her pronunciation and timing was heavily affected.*

P7: At first it was easy, but with the increase of the latency effect, it became difficult to sing. I had to now concentrate while I sing.

OC: *Participant started singing louder. I also noticed that she started dragging her notes and this influenced her timing.*

P8: Uhm, I'm going to describe it as musical seasickness because it was like my hands are playing, but my ears are like, no, they're not, and then it's a whole little discrepancy happening there and it's very unpleasant. Uh, so it made it a lot more difficult to play. And then sometimes I'd try play something and then obviously I wouldn't hear it, so my fingers would try play it again, a little muscle-memory kicking in and their [sic] like a little spasm, fun.

OC: *Participant started rushing and this made her lose her timing. At times, she also played slower.*

P9: Yes, I started rushing because the latency, uhm, affected my timing.

OC: *Participant started playing faster (and some places slower).*

P10: I feel that I had to tap my foot and concentrate more to stay on the beat and in time.

Researcher: Please state the extent of your formal music training, if any?

P1: Well, I've been playing guitar for about roughly eight to nine years and I also have drums for about five years, and I'm also currently studying music production and sound engineering at Emendy College.

P2: My music training involved completing a Bachelor's degree in music where guitar is my main instrument and then I also completed a Master's degree in music, uh, where I was involved with music science, scientology, musicology, uhm—wat moet ek nog sê?

P3: Uhm, I studied at a music college. Uh, it was TOM Arts College and I studied a three-year course, uhm, did guitar as main instrument. I had musical theory, ear training, history, uhm, performance, uhm, band dynamics and so forth.

P4: Well I've been playing—basically I've been doing singing training since I was about seven. Uhm, first I started with classical training, which I did not like, and then I went over to my current teacher where she taught me how to sing. So I've been doing it since I was about seven. And I did—uhm, I did grade 1 to grade 8 singing through Trinity and 1 to 6 music theory.

P5: No training.

P6: Hi Waldo. I have grade 8 Rockschool training, as well as Trinity grade 8 in vocals specifically.

P7: Uhm, I'm taking vocal training classes and also do vocal exercises every day.

P8: Uh, I've been in a choir for two years before and I have done about seven years vocal training, which I've recently stopped. Uh, I can play a didgeridoo, which is a fun time. Uhm, I bought a saxophone to just play around with. I don't want to make it official; I don't want to have lessons for that purpose. I have had musical training in the past. Uhm, I also did a year of drums and a year of guitar, and as far as piano, I did a year in grade 7 and then stopped completely, up until now, which is quite a few years later. Uhm, and then I've had like four months of training now, but I'm a beginner again because it's all gone pretty much.

P9: Well, I studied music and, uhm, played the piano about 13 years now.

P10: I have got a classical diploma in music performance through Royal Schools and I studied four years at TUT, light music.

Researcher: In what ways did playing with the metronome influence your ability to perform with the latency?

P1: Well, there's a lot more room for error, so basically with—when you're playing by yourself, you can, uh—you can basically go off of time without really it having any affect, but once you add a click, it has to be specific to the click.

P2: The metronome made it much easier. Uhm, I could switch off the music in my head and try to listen exclusively only to the metronome, which made it easier to perform.

OC: Upon examining the waveform, it is noticeable that the participant ended on time when she played with the click.

P3: Uh, it was a better guide for me because then I knew this was—uhm, I remember watching my hand when I was strumming and listening to the click alone, trying to ignore the latency and that helped me, but it really—yeah, it was pushing it, but, uhm, the click really helped with the latency in that sense.

P4:   Uhm, in the beginning I thought, okay, maybe I could use this, and I tried to play with it and I sort of got it right, but then later on it just became an irritation and then I tried to ignore it and then it was just a noise in the background.

OC: I noticed that she has difficulty playing with the metronome. This might be due to her lack of experience playing with a click-track?

P5:   Yes, it did help me to stay in the correct rhythm.

P6:   It was a lot better, except for the last two repeats I sort of—like I just said, I had to stop to hear the click-track and then I could move forward.

P7:   It helped me to keep time.

P8:   Well, apparently, according to external observation, it made it a lot more consistent and it gave me something else to, uh, rely on that was consistent because the playing clearly wasn't and didn't match up with I was hearing. Uh, but for me at the time, it made it more confusing because you have a metronome which is consistent and accurate and then you're playing which really isn't and doesn't match up, so it's just like an extra, added-on, horrible little storm to the musical seasickness.

P9:   Yes, it gave me a clear guide to follow as the latency got too much.

P10:   Uhm, it was actually quite distracting, yeah. To be honest, I prefer to play without it.

Researcher: Have you ever recorded in a studio before, and if yes, have you been exposed to click-track recording methods?

P1:   Yes, I have.

P2:   No, neither of the above.

P3:   Yes, I have been recording, and yes, I have been, uhm, friends with the click for many years.

P4: I've recorded in a studio multiple times, but the click-track was basically just the intro one, two, three count and then you start singing, that's all. I haven't heard the clicking while you play, no.

P5: No, never recorded in a studio.

P6: Yes, I've recorded in a studio, and yes, I've recorded with a click-track.

P7: Yes, yes to both.

P8: Uh, I've recorded in a studio, uh, only for vocals though, but no click-track recording at all.

P9: Yes, I do have a lot of studio experience and I'm also used to working with a click-track.

P10: Yes, I have, to both.