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Hand-Arm Vibration Exposure in Drummers

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By

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ABSTRACT

Due to the physically intense nature of the activity, drummers (i.e., percussionists who play the drum set) are exposed to a variety of factors, including hand-arm vibration (HAV), that put them at increased risk of developing playing-related musculoskeletal disorders (PRMDs). The purpose of this study was to examine HAV exposure in drummers through realistic playing scenarios. Specifically, this study examined vibrations (i.e., frequency-weighted RMS accelerations) recorded at the hands. Six male drummers played three songs of their choosing with one accelerometer placed on the right hand, then repeated the same three songs with the accelerometer placed on the left hand (average playing time of 11.9 minutes per set). Extrapolated A(8) values [A(8)e] were calculated based on the participants' self-reported typical daily playing time and were compared to the American Conference of Governmental Industrial Hygienists (ACGIH) action limit (AL: 2.5 m/s^2) and threshold limit value (TLV: 5.0 m/s^2) for HAV exposure. Drummers experienced an average A(8)e of 5.7 m/s^2 in the left hand and 6.7 m/s^2 in the right hand, which exceeded the ACGIH AL (2.5 m/s^2) and TLV (5.0 m/s^2) values. Three of the six participants registered A(8) values that exceeded the AL and TLV within the data collection session alone (i.e., without extrapolating based on typical daily playing time). The results demonstrated that drummers are exposed to 8-hour equivalent HAV magnitudes that are similar to those recorded during industrial and athletic tasks. Further HAV exposure analyses with larger sample sizes and incorporating more realistic playing scenarios (i.e., live concert performances) across multiple musical genres and varying drummer skill levels are warranted.

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ABBREVIATIONS

Abbreviation	Description
ACGIH	American Conference of Governmental Industrial Hygienists
AL	Action Limit
ANSI	American National Standards Institution
CTS	Carpal Tunnel Syndrome
EE	Energy Expenditure
EMG	Electromyography
HAV	Hand Arm Vibration
HR	Heart Rate
Hz	Hertz (Frequency)
ISO	International Organization of Standards
MIDI	Musical Instrument Digital Interface
MVO_2	Myocardial Volume Oxygen
PRMD	Playing-related Musculoskeletal Disorder
RER	Respiratory Exchange Ratio
RMS	Root Mean Square
ROM	Range of Motion
RPE	Rate of Perceived Exertion
RULA	Rapid Upper Limb Assessment
TLV	Threshold Limit Value
VAS	Visual Analogue Scale
WMSD	Work-related Musculoskeletal Disorder

GLOSSARY

Acceleration	The change of time and velocity of a moving object (a = v/t). (Marras & Karowski, 2006)
Accelerometer	A device designed to convert mechanical motion into a corresponding electrical charge proportional to current acceleration. (Marras & Karowski, 2006)
Anthropometry/anthropometrics	The science of measuring the human body which can be useful to researchers, engineers, and designers to design products based on average or specific body segment lengths, widths, and depths. (Marras & Karowski, 2006)
Carpal Tunnel Syndrome (CTS)	Symptoms of numbness/tingling or burning sensations on the palmar surface of the hand (i.e., thumb, index, middle, and ring fingers). Caused by compression or irritation of the median nerve as it passes through the carpal tunnel formed by the wrist (carpal) bones and the transverse carpal ligament. (ISO-5349-1, 2001)
Closed Hi-Hat/Snare Pattern	A drum set that is arranged based on handedness of the drummer (i.e., right-handed drummer; the hi-hat is played with the right hand while the snare is played with the left in a crossed arm position).
Force	As per Newton's Second Law, the product of mass and acceleration (F = m*a). Metric unit is the Newton (N) (i.e., 1N = 1 kg m/s^2). Muscular force is the muscle tension multiplied by the transmitting cross-sectional area. (Marras & Karowski, 2006)
Frequency	The number of times that a wave repeats itself within a particular period (i.e., one repetition/one second [Hz]). (Cambridge Dictionary, 2022).
Hand Arm Vibration Syndrome (HAVS)	Complex neurological, vascular, and musculoskeletal signs/symptoms associated

	with disorders produced by hand-transmitted vibration. (ISO-5349-1, 2001)
Prevalence	“Number of existing cases of disease or disorder in a given population at a specified time.” (ISO-5349-1, 2001)
Resonance	The tendency of an object to (1) move in concert with an external vibrating source and (2) to internally amplify the impinging vibration from that source; resonance is the optimum energy transfer condition between the source and the receiver. (Marras & Karowski, 2006)
Session Drummer	A drummer who is hired by a band or on a contract basis to fill in for live performances or recordings. (O’Connor, 2022)
Shock-Type Excitation Impacts	A random, non-periodic vibration produced by striking an object or surface, resulting in “shock” vibrations travelling through the hand or body (ISO-5349-1, 2001). Shock is described as “a sudden change in …acceleration that excites transient disturbances in a system.” (ISO 2041, 2018, p. 31)
Strain	The change in length over the resting length of a structure, referred to as a deformation point, in which the structure is under loading (change in length/rest length). (Potvin, 2014)
Stress	The load per unit area that develops on a plane surface within a structure in response to an external load (N/cm^2). (Potvin, 2014
Tendinitis	Inflammation of a tendon. (ISO-5349-1, 2001)
Vibration	Vibration is the oscillatory motion of bodies. Any body that has mass and elasticity is capable of vibration, which include powered machines, structures, and even the human body (Chaffin et al., 2006).

CHAPTER 1: INTRODUCTION

1.0 Introduction

The effort and physical ability drummers need to execute skilful tasks during a performance is often underestimated (De La Rue et al., 2013; Romero et al., 2016; Azar, 2020). Due to the physically intense nature of the activity, drummers are exposed to a variety of factors that put them at increased risk of developing injuries (Cuden et al., 2015; Wagner, 2016; Roseiro et al., 2018). Such injuries, called playing-related musculoskeletal disorders (PRMDs), are a very common occurrence in drummers. Azar (2020) recently conducted an online survey of drummers' experiences with PRMDs and reported that 68 % of participants experienced a PRMD at some point during their musical lifetime. Fifty nine percent of the study participants reported PRMDs in the upper limb and 25 % reported PRMDs specifically in the wrist (Azar, 2020). To reduce the prevalence of PRMDs, specific risk factors that lead to their development must be identified.

Hand-arm vibration (HAV) is quantified through the transmission of periodic, random non-periodic and/or repeated shock-type excitation impacts through the hand and arm (ISO 5349-1, 2001). Exposure to HAV is common in operators of hand-held machines such as jack hammers, lawn mowers, and coal drills in mining operators (Kunimatsu & Pathak, 2012). Truck drivers and lawn maintenance staff can also be exposed through hand contact (e.g., steering wheel, tools, machines, etc.; Thrailkill et al., 2012). Cyclists experience HAV through the repetitive wheel bounces while riding on the road, which transmits vibrations through the handlebars to the hands/forearms (Chiementin et al., 2019). However, HAV can also occur from repetitive impacts due to using the hands or tools to strike against solid objects. For example, a tennis player performing a backhand stroke can experience shock-type excitation impact vibrations through the forearm (Knudson, 2004). Automotive assembly line workers can experience repeated hand or tool impacts while installing window weather stripping (Potvin et al., 2000) or using an impact wrench (Radwin et al., 1990). Similarly, drummers are exposed to HAV through impacts of the drumsticks on the drum set to produce sound (Roseiro et al., 2018).

Over-exposure to HAV has been linked to chronic injuries such as HAV syndrome, carpal tunnel syndrome, tendinitis, and Raynaud's syndrome (Roseiro et al., 2018). Symptoms of over-exposure to HAV can include finger blanching, nerve entrapment or numbness/tingling, inflammation, and pain, which can be early signs of vascular and/or neural damage (Roseiro et al., 2018). Carpal tunnel syndrome (CTS) and tendinitis are the two most frequently reported drumming-related injuries (Azar, 2020). Therefore, further understanding HAV exposure in drummers is warranted to reduce their risk of developing PRMDs related to HAV exposure.

The International Organization of Standards (ISO) provides guidelines for measurement device specifications, measurement/evaluation techniques, and the definition of vibration exposure. HAV exposure is measured using accelerometers and is reported as frequency-weighted RMS accelerations (units: m/s^2: ISO 5349-1, 2001). RMS accelerations are measured along the three coordinate axes of movement (X = anteroposterior, Y = mediolateral, and Z = superior/inferior) to better understand each direction of acceleration acting on the hand and arm (ISO 5349-1, 2001). It is important to note that applying these standards to assess repeated shock-type excitation vibrations should be done with caution, as the ISO standards do not address the full relationship between the magnitude, frequency, daily, and cumulative vibration exposure and tissue injury/disorders (ISO 5349-1, 2001). The guidance of ISO 5349-1 and 5349-2 is based on limited quantitative data available in both practical experience and laboratory experimentation, but it does provide the public with measures to help protect most workers against serious vibration disorders and impairments from hand-transmitted vibration (ISO 5349-1, 2001). Despite this limitation in applicability, other studies have applied the ISO standards in the analysis of repetitive hand impacts (e.g., Potvin et al., 2000; Roseiro et al., 2018). Therefore, these standards are currently the most valid method available to analyze drumming-related HAV.

Although drummers are clearly exposed to HAV while playing their instrument, very little research has been conducted on HAV exposure in drummers. To date, a pilot study by Roseiro et al. (2018) is the only research on this issue. They reported average frequency-weighted RMS accelerations for six participants (three musically trained [MT] and three non-musically trained [NMT]). The MT participants recorded frequency-weighted RMS accelerations of 4.3 m/s^2 in the left hand and 6.2 m/s^2 in the right hand while the NMT participants recorded 12.9 m/s^2 and 14.5 m/s^2 in the left and right hands, respectively. The 8-hour daily vibration exposure [i.e., A(8)e] for the MT participants was 3.0 m/s^2 in the left and 4.4 m/s^2 in the right hand. The A(8)e values recorded in NMT participants were 6.5 m/s^2 and 7.3 m/s^2, respectively. A(8)e values for MT drummers were calculated based on four-hour playing sessions, while the calculations for the NMT drummers were based on two-hour playing sessions. By comparison, Kunimatsu and Pathak (2012) documented frequency-weighted RMS accelerations of 0.5-2.3 m/s^2 in mining operators using power shovels. Thrailkill et al. (2012) assessed a sulky accessory for a commercial walk-behind lawn mower and reported average A(8) values of 0.8 m/s^2 (X = anteroposterior), 1.0 m/s^2 (Y = mediolateral), and 1.3 m/s^2 (Z = superior/inferior) in 12 participants over a duration of 107 minutes. The American Conference of Governmental Industrial Hygienists (ACGIH) mandates that individuals who participate in an 8-hour work period should not be exposed to frequency weighted RMS accelerations greater than 5.0 m/s^2 in the upper limb (ISO 5349-1, 2001). At RMS accelerations of 2.5 m/s^2, standards and regulations of equipment should be set in place for protection of employees who experience vibration exposure at work (ACGIH, 2019). Therefore, drummers appear to be exposed to moderate levels of HAV risk and ergonomic/protective measures should be warranted based on the A(8)e values documented in MT drummers (3.0 m/s^2 – 4.4 m/s^2) and NMT drummers (6.5 m/s^2 – 7.3 m/s^2; Roseiro et al., 2018).

While Roseiro et al. (2018) were the first to report HAV exposure in drummers, the study design was limited by short playing times and a low participant sample size. The authors monitored HAV for only 180 seconds of drumming, and they only included six participants in their study. Furthermore, the 180 seconds of playing time was described as a “complete musical piece”, however, the authors did not specify whether this was a song (nor the musical genre) or standardized musical piece (i.e., a standardized drum pattern). Most drummers reported playing the drums for an average of 5-15 hours/week (Azar, 2020), and a typical professional performance can range from 25-161 minutes in duration without breaks (Azar, 2021b). Given the substantial proportion of drummers who experienced upper limb PRMDs (Azar, 2020), further investigation to document HAV exposure in drummers under more realistic playing conditions is warranted.

1.1 Statement of Purpose/Hypothesis

The purpose of this study was to examine HAV exposure in drummers through realistic playing scenarios. Specifically, this study examined vibrations (i.e., frequency-weighted RMS accelerations) recorded at the hands. Extrapolated A(8) values [A(8)e] were calculated based on the participants' self-reported average playing time and were compared to the ACGIH (2019) action limit (AL: 2.5 m/s^2) and threshold limit value (TLV: 5.0 m/s^2) for HAV exposure. Based on previous research reporting A(8)e values of 3.0 m/s^2 and 4.4 m/s^2 over 180-second playing times in MT drummers (Roseiro et al, 2018), it was hypothesized that participants will show A(8)e values above the ACGIH AL and TLV for HAV exposure (2.5 m/s^2 to 5 m/s^2) in both hands. The results of this study will provide a starting point to help others make evidence-based suggestions for improvements to drumming equipment (sticks, cymbals, drumheads, etc.), playing technique, and musical training. Further research studies could be developed to examine the effects of muscle activation, joint angles, and vibration attenuation (i.e., gloves, dampening rings, drumhead tensions, etc.) on HAV exposure in drummers.

CHAPTER 2: LITERATURE REVIEW

2.0 Description of Drumming

A 'drummer' is an individual who plays the drum set with the use of all four limbs while in a seated position (De La Rue et al., 2013; Romero et al., 2016; Colwell, 2017; Roseiro et al., 2018; Azar, 2020). The art of drumming was developed by ancient civilizations who created sound and rhythm by striking mallets or sticks against different objects (Colwell, 2017). Membranophone percussion instruments produce sound when a membrane is struck with a stick or percussive tool (Colwell, 2017). These percussive sounds evolved into multiple genres of classical and orchestral music that included different uses of cymbals, bass drums, snare drums, and toms. Each piece vibrates differently to create specific sounds, and the volume of each note is dependent on the force used to strike the specific membrane or cymbal (Colwell, 2017). These instruments can be combined into the modern known 'drum set'.

Standard drum sets include four pieces: a snare drum, a mounted tom, a floor tom, and a bass drum with a foot pedal. These instruments are tuned differently to create a specific sound from striking the tip of the drumstick against a membrane. The crash, ride, and hi-hat cymbals round out the rest of the drum set to add different time-keeping elements and musical accents (Colwell, 2017). The chair (throne) is the most important piece to dictate the position of the rest of the drum set (Colwell, 2017). The snare drum is positioned directly in front of the player as it is the most frequently used piece of equipment. The feet are placed on either side of the snare drum with the bass drum pedal under the right foot and hi-hat pedal under the left foot at a comfortable position for the drummer (Colwell, 2017). The mounted toms are placed at chest height and flow to the floor tom on the far-right side of the throne. Lastly, the ride and crash cymbals are placed on the outskirts of the reach zone, with the crash on the left and the ride on the right, respectively. This is the typical set-up for a right-handed drummer; left-handed drummers would set up the drum set in reverse.

With respect to the striking implements, drumsticks are typically made from oak, hickory, or maple wood due to their light weight, durability, and responsiveness to sound (Zoutendijk, 2017). The drumsticks are held in specific ways (i.e., grips) depending on which piece of equipment is played. The German matched grip (i.e., palms facing down, forearms pronated, motion of the wrist involves flexion/extension) is typically used for the snare drum (Feldstein & Black, 1987; Colwell, 2017), whereas the French matched grip (i.e., elbows at mid-supination, motion of the wrist involves radial/ulnar deviation) is used to aid in reaching the toms and cymbals and for quick movements (Feldstein & Black, 1987; Colwell, 2017). These grip styles are illustrated in Figure 1. However, the overall comfort and style of the drummer is adapted through practice for finesse during a

Figure 1. German (left) and French (right) matched stick grips. Images used with permission from Dr. Nadia Azar.

performance. New or different grip styles may be adopted to better suit the style or performance of the drummer.

Once the drum set is adjusted to fit the drummer, their task is to control the rhythm, tempo, and volume of striking the drum set to enhance the music and to keep the rest of the band in time (Mauch & Dixon, 2012; Colwell, 2017). Mauch and Dixon (2012) stated that a drumbeat tracks a temporal grid on the piece of music, acting as an anchor for other descriptors in the musical piece (e.g., guitar, singer, etc.). When the beat is controlled, the tempo or speed of the song can be matched by the rest of the musicians in the piece (Mauch & Dixon, 2012). Therefore, the importance of a drummer is not only to produce sounds within the musical piece; they also orchestrate the rhythm and keep the rest of the instruments on time.

2.1 Physical Demands of Drumming

Drummers experience energy expenditures, rates of oxygen consumption, and cardiovascular activity at similar levels to professional athletes (i.e., running, cycling, field/ice hockey, and volleyball (De La Rue et al., 2013; Romero et al., 2016; Azar, 2021a). De La Rue et al. (2013) demonstrated that drumming during rock/pop themed concerts is associated with high energy expenditures. Fourteen professional and semi-professional drummers completed two laboratory tests during which their maximum oxygen consumption (MVO_2) and heart rate (HR) were monitored (De la Rue et al., 2013). These tests included drumming and cycling tests (both to exhaustion) to compare the two actions. Energy expenditure (EE, units: kcal) was calculated using the respiratory data according to thermal equivalents of MVO_2 and the respiratory exchange ratio (RER; De la Rue et al., 2013). A linear regression was then developed to characterize the relationship between HR and EE, which could then be used to estimate EE based on the HR recorded during the live performances (De la Rue et al., 2013). The drummers' HR were then monitored during live performances of 60 minutes in length. The average EE during live performances was 623 kcal, and the average peak HR was 186 beats per minute (bpm; De la Rue et al., 2013). De La Rue et al. (2013) concluded that previous studies underestimated energy expenditure in rock/pop genre drumming and the metabolic demands of drumming were equal to those of running, cycling, ice and field hockey, and competitive volleyball. Romero et al. (2016) conducted a similar study, which examined metabolic exchange rates through MVO_2, minute ventilation (V_e), and RER for five semi-professional male heavy metal drummers (Romero et al., 2016). Each participant underwent a 20-minute drumming test (four metal/rock songs and four songs of their choosing) and a VO_2 max cycle ergometer test 20 minutes after their drumming test was complete (Romero et al., 2016). The authors reported the drummers' VO_2 levels reached 90 % of their MVO_2 while performing at intense speeds (Romero et al., 2016). Peak MVO_2, V_e, and RER levels averaged 33.5 ml/kg/min, 56.1 L/min and 0.9 (VCO_2/VO_2), respectively. Based on these data, Romero et al. (2016) concluded that drumming could be placed in the "vigorous intensity activity" category on the Borg rating of perceived exertion (RPE) scale (Borg, 1998). Finally, Azar (2021a) reported EE levels and HR of 39 professional drummers during live performances. These professional drummers represented many genres of music including pop, rock, heavy metal, and country. Azar (2021a) reported similar EE levels and HR to De La Rue et al. (2013) and Romero et al. (2016) – the average rate of energy expenditure was 10 Calories/min (range: 3-14) and the average HR was 144 bpm (range: 76-175). Given the high physical demands associated with drumming performances, a description of the rates and risk factors of PRMDs in drummers is warranted.

2.2 Prevalence of PRMDs in Drummers

Many athletic and occupational tasks are strenuous, and drumming is clearly no exception. Given the substantial physical demands, mental agility, multi-limb coordination, and equipment needed to play the drums, it comes as no surprise that drummers are at risk of developing PRMDs. Sandell et al. (2009) conducted a survey of 279 percussionists ranging from classical to drum set instruments. In membranophone percussionists (drum set and timpani), 77.4 % experienced PRMDs, and the body regions with the highest PRMD rates were the hands (right: 48.7 %, left: 48.7 %; Sandell et al., 2009). Hawkins et al. (2015) investigated 38 university level percussionists, 31 of whom primarily played the drum set. Seventy-seven percent of the study population reported having experienced at least one PRMD over their lifetime, the majority of whom reported PRMDs of the upper limb. Recently, Azar (2020) conducted a survey to better understand the rates and patterns of PRMDs specifically in drummers. A total of 865 drummers participated in the study. Of the 831 valid responses, 68 % of the participants reported a lifetime history of a PRMD, with most participants reporting PRMDs in multiple areas of the body (59 %). The upper limb (i.e., shoulder, arm, elbow, forearm, wrist, hand) was the most frequently affected location on the body (59 %). The wrist was the most common of the upper limb PRMD locations (25 %). These three studies reported similar rates of PRMDs in drummers (68-77 %) with consistent rates of PRMD in the upper limb (49-59 %) (Sandell et al., 2009; Hawkins et al., 2015; Azar, 2020). Therefore, investigation of specific risk factors leading to upper limb PRMDs in drummers is justified due to high rates of PRMDs in drummers, especially in the upper limb.

2.3 PRMD Risk Factors

Understanding drummer-specific risk factors is an important step to reducing the prevalence of PRMDs in this group. PRMD risk factors can be divided into four general categories: individual, psychosocial, environmental, and physical risk factors. Examples of individual factors include sex, body mass index (BMI), age, and race (Sandell et al., 2009). Psychosocial risk factors arise from the culture, policies, expectations, and social attitude of an organization or person (Canadian Centre for Occupational Health and Safety [CCOHS], 2021). Environmental risk factors are influenced by the surrounding environment of a workplace or workspace (Al-Omari & Okasheh, 2017). These can include visibility, temperature, sound, space (i.e., workplace station), and air quality (Al-Omari & Okasheh, 2017). Lastly, physical risk factors include posture, equipment usage, frequency, duration, and force (Armstrong et al., 1987; Putz-Anderson et al., 1988; Moore et al., 1991; Bernard et al., 1997, ISO 5349-1, 2001; da Costa & Vieria, 2010).

Harkness et. al (2004) conducted a two-year prospective cohort study using a questionnaire to determine work-related physical, psychosocial, and environmental risk factors as predictors in developing new onset chronic pain in healthy individuals. The results revealed a positive association of the combination of physical (i.e., monotonous/repetitive workload, lifting, pushing, pulling, etc.), environmental, and psychosocial risk factors and the development of new onset chronic pain, with physical and psychosocial risk factors (i.e., monotonous/repetitive work) showing the greatest positive associations, particularly when they are present in combination. The study did not find any evidence of environmental factors as a lone contributor to the development of new onset chronic pain, however, the presence of monotonous/repetitive work could be a factor in enhancing the effects of individual psychosocial risks such as job stress. This study suggests that physical risk factors are a primary predictor in developing new onset chronic pain in healthy individuals.

Drummers may be exposed to these risk factors while playing the drums or while setting up or taking down equipment (physical), interacting with the crowd/band members or playing difficult musical pieces (psychosocial), or while playing on stage through spotlights, air quality of the venue, and loud noise from the instruments and crowd (environmental). While environmental, psychosocial, and individual factors are all important contributors to the development of PRMDs in drummers and their interference with work/playing the drums (Sandell et al., 2009; Hawkins et al., 2015), the focus of this study will be on physical risk factors.

2.3.1 Force

Both high- and low-magnitude forces are risk factors for injury to the body's musculoskeletal system in everyday sport, work, and active daily living. High forces can cause traumatic injury, which occurs when a force or stress that exceeds the tissue's tolerance is applied a single time (McGinnis, 2013). For example, this type of injury occurs during high-impact collisions (e.g., the MCL ligament rupturing from a direct blow to the lateral side of the knee; McGinnis, 2013). On the other hand, forces or stresses that are within a tissue's tolerance that are applied repeatedly can also lead to overuse injuries (McGinnis, 2013). An example of this type of injury is anterior shin pain that develops from repeated foot impacts during long-distance running (McGinnis, 2013).

This may be considered an overuse injury as a single running stride is unlikely to be the cause of the fracture. Instead, the fracture results from the number of repetitions and magnitude of the stress to create the discomfort in an individual (McGinnis, 2013).

Gallagher and Heberger (2012) conducted a systematic literature review of 12 studies to examine the relationship between force and repetition in developing musculoskeletal disorders (MSDs). Ten of the twelve studies observed and managed force and repetition, however, they did not evaluate their interaction in developing MSDs. Upon reviewing these studies, Gallagher and Heberger's (2012) overall conclusion was that there is a force by repetition interaction with respect to tissue damage. Secondly, increased repetition in low force tasks leads to a modest MSD injury risk, however, MSD injury risk can be significantly increased with higher forces or higher frequencies. Therefore, the higher the magnitude of the load (force), the fewer repetitions are needed for injury to occur and the lower the magnitude of the load, the more repetitions needed to develop an injury (Gallagher & Heberger, 2012; McGinnis, 2013). An overuse injury develops faster if there is not enough rest time for tissue remodelling (McGinnis, 2013). Therefore, either the frequency, rest time, and/or magnitude of the load must change to reduce risk of injury.

The biomechanics of injury is related to the mechanical tolerance of a tissue, in other words, the tissue's ability to withstand the application of an external load without being damaged (Potvin, 2014). Musculoskeletal tissues have elastic capabilities, where they can undergo deformations under applied external forces (N) or stresses (N/cm^2) and return to their original length/shape to a certain degree (Potvin, 2014). However, when the capacity of a tissue reaches the yield point, the tissue will no longer return to its original length/shape – this is known as “plastic” deformation (Potvin, 2014). The tissue’s tolerance depends on its ability to withstand a load (Potvin, 2014). If the load applied to a tissue is greater than its ability to withstand it, a failure point occurs and injury to the tissue can result (Potvin, 2014). Figure 2 gives a visual representation of a generalized stress/strain curve, which describes the relationship between the stress applied to a tissue and the tissue’s resulting deformation (strain).

Wolff’s law describes a tissue’s ability to adapt to the mechanical demands placed on it within its tissue tolerance (Potvin, 2014). This is true when the mechanical demands placed on the tissue (i.e., bones, muscles, ligaments) are within the tissue’s capacity to return to its original length when the load is removed (i.e., the elastic region in Figure 2). A tissue can withstand forceful and repetitive loads within its strength capacity, creating a

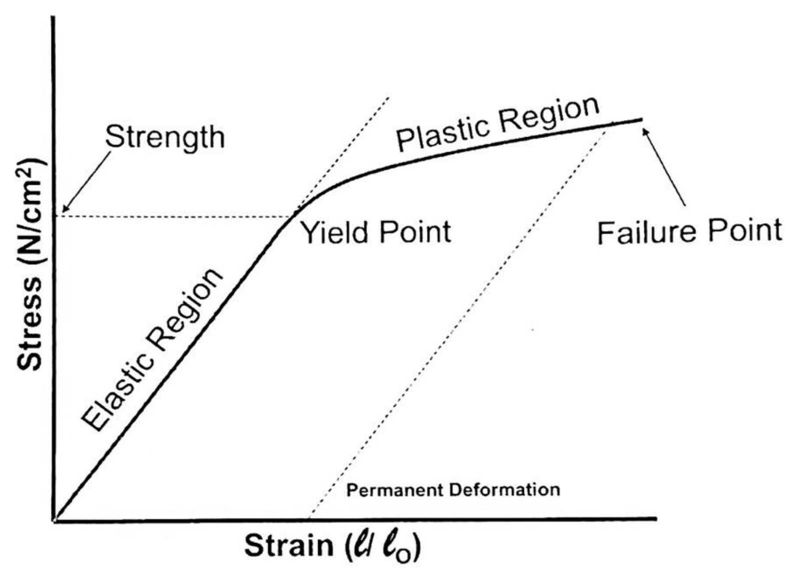

Figure 2. Generalized representation of the stress/strain relationship. When an applied stress and the resulting strain exceed the strength of a tissue (i.e., the yield point), permanent changes to the tissue’s length occurs. Strain is the ratio of the change in the tissue’s length (L_i) to its original length (L_0). Stress is the load (N) per unit area (cm^2) that develops on a plane surface within a structure in response to an external load (Image used with permission: Potvin, 2014, p. 18).

training effect and tissue growth. If the tissue experiences a load that is too forceful, repetitive, or prolonged, permanent change and injury will occur (Potvin, 2014). However, if a tissue does not maintain its capacity with proper loading, repetition, and duration, the tissue can atrophy, resulting in weakness and fatigue (Potvin, 2014). Therefore, based on Wolff's Law, it is important to maintain a healthy tissue capacity to decrease injury risk. Figure 3 illustrates Wolff's Law and the ideal balance between repetition and loading to maintain the strength capacity needed to complete task demands (i.e., a training effect).

Several studies have examined the relationship between force and workplace injury. Bernard et al. (1997) reviewed eleven epidemiologic studies to determine whether there was an association between force and carpal tunnel syndrome (CTS). Four of the eleven studies showed strong evidence for a positive relationship between force and CTS, meeting all the pre-determined criteria (strength of association, consistency, temporality, and exposure-response relationship). Bernard et. al (1997) describes the pre-determined criteria as follows: strength of association is the degree of the relationship between

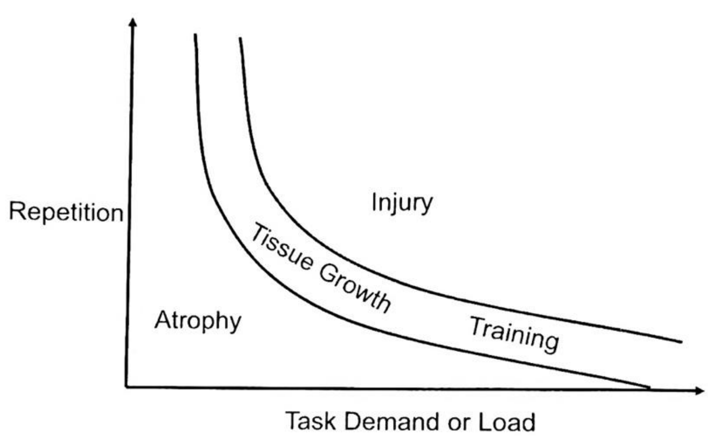

Figure 3. Wolff's Law. The tissue's capacity to withstand repetitive and forceful loads reducing injury and atrophy risk (Image used with permission: Potvin, 2014 p. 20).

multiple variables (i.e., repetition and force); consistency of the relationship is reported through the number of studies showing the same results; temporality measures the existence of the relationship over time, usually in longitudinal studies; and lastly, exposure-response compares the efficacy of cause (i.e., force) in the relationship to the effect (i.e., injury). The authors also reviewed eight studies to determine whether there was an association between force and wrist tendinitis. Five of the eight studies showed strong evidence of a positive relationship between force in combination with other risk factors (repetition, duration, and posture) and tendinitis injuries, and one study reported evidence of force being a lone factor, in the development of wrist tendinitis. Lastly, Bernard et al. (1997) reviewed twenty epidemiological studies for an association between force and elbow tendinitis (epicondylitis). Thirteen of the twenty studies reported evidence of a positive association between force/repetitive work and epicondylitis. Therefore, forceful exertions in occupational tasks are positively associated with wrist and elbow injury diagnoses.

As stated above, a drummer must control both the tempo and dynamics of a musical piece while playing. More forceful impacts are required to play louder dynamics. Wagner (2006) reported drummers playing *piano* (soft sound) produced forces of approximately 3 N at the tip of the drumstick, while playing *forte* (loud) produced forces of over 100 N and peak forces registered over 200 N (Wagner, 2006). By comparison, Potvin et al. (2000) reported that automotive workers using hand impacts to mimic the installation of weather stripping around a car window registered an average of 235 N of force per impact over a 4-hour period (Potvin et al., 2000). Therefore, the intensity of the effort needed to strike a drum set approaches that of forceful impacts during physical workplace tasks.

2.3.2 Repetition

Repetition is another risk factor for developing musculoskeletal injuries. As stated above, an injury can be acquired through either a single application of a high force, or through repetitive applications of high or low forces. With increased frequency, stresses applied to the musculoskeletal tissues will either create a training effect or lead to an overuse injury, depending on the strength and mechanics of the tissue (McGinnis, 2013). In overuse injuries, the repetitive application of low magnitude stresses to musculoskeletal tissues leads to microtears, resulting in injury (i.e., tendonitis, fractures, muscle tears; McGinnis, 2013). These microtears need “remodelling” or tissue healing by reducing the loading frequency (McGinnis, 2013). If there is insufficient recovery time, micro tearing will continue to occur and will progressively decrease the tissue’s ability to tolerate loads that it was once able to handle for extended durations (Potvin, 2014). Figure 3 (above) gives a visual representation of the relationship between the magnitude and frequency of the application of loads to musculoskeletal tissues.

There are multiple examples of occupational overuse injuries due to repetitive limb movements. Armstrong et al. (1987) conducted a cross-sectional study of 652 industrial workers to examine the difference between high and low repetitive force tasks during an 8-hour workday. Electromyography (EMG), video, physical examination, and interviews were used to analyze the prevalence of hand injuries in workers of various jobs (i.e., sewing, appliance installation, bearing fabrication, bearing assembly, investment molding, and electronics plants). Workers were then categorized into groups based on their job repetitiveness (video analysis) and force output (EMG). Using a physical examination and/or an interview with the examiners, the authors determined that 12 % of the total study population (N = 652) fit the criteria for hand and forearm injury (e.g., tendinitis/tenosynovitis, trigger finger, de Quervain's disease). Between 3.5 % and 10.8 % of the workers with high repetition jobs experienced a hand and/or forearm injury. Bernard et al. (1997) summarized over 30 epidemiologic studies examining physical workplace factors (i.e., force, repetition, duration, and posture) and carpal tunnel syndrome (CTS). Five studies reported evidence for a positive association between CTS and high repetition as a lone factor, while nineteen studies reported strong evidence for a positive relationship between CTS and repetition in combination with other workplace factors. Therefore, there is evidence to support repetition as a risk factor exclusively and in combination with force, posture, and duration of work-related tasks.

A drummer can strike the drum set thousands of times within a playing session or performance. Mauch and Dixon (2012) randomly sampled 100 songs from over 48,176 different Musical Instrument Digital Interface (MIDI) internet files, from which they identified over 4.8 million bar-length drum patterns. Cuden et al. (2015) sampled the first 510 drum patterns from Mauch and Dixon's (2012) study to determine drum set piece strike frequency. The authors counted the number of strikes against each of the drum set pieces (summarized in Table 1). The results were expressed in strike count and percentage, with the hi-hat cymbals having the highest strike frequency at 4.6 million out of 6.8 million strikes or 68.9 % (Cuden et al., 2015). While the hi-hat cymbals constituted most of the drum set strikes, 6.8 million strikes within 510 drum patterns demonstrates the magnitude of the repetition involved in playing the drum set. Therefore, strike

Table 1. Drum piece strike frequency rankings. Cuden et al. (2015) calculated these strike frequency rankings based on 510 drum patterns identified by Mauch and Dixon (2012). Table reproduced from Cuden et al., 2015 (p. 4446).

Ranking	Drum Piece	Strike Frequency	Percentage (%)
-	Bass Drum	2,063,050	-
1	Hi-hat	4,664,094	68.9
2	Snare Drum	1,438,762	21.3
3	Ride Cymbal	576,229	8.5
4	Crash Cymbal	65,120	1.0
5	Toms	25,443	0.4
Total		6,769,650	100

frequency is likely to be a large contributor in the probability of developing PRMDs while drumming.

2.3.3 Posture

Static and/or awkward (non-neutral) postures are another risk factor for developing musculoskeletal injuries. The postures a worker must adopt are influenced by the task, workstation, tool design, and anthropometrics of the worker (Vieira & Kumar, 2004). Awkward postures can increase the amount of force needed to complete a task, which can lead to nerves, tendons, and blood vessels being compressed within the body (Occupational Health and Safety Administration [OSHA], 2020). For example, when a worker’s wrist is in a flexed position, the tendons and tendon sheaths can rub against bones and ligaments, causing inflammation of the tendon sheaths known as tendinitis (OSHA, 2020). Furthermore, holding postures for long periods of time (i.e., ‘static postures’) can be detrimental to the musculoskeletal system, particularly if they are non-neutral postures (Armstrong et al., 1993; Callaghan & McGill, 2001; Nur et al., 2014; Cuden et al., 2015). Non-neutral postures result in increased distance between an agonist muscle's insertion and the joint axis of rotation (i.e., moment arm), which requires increased moments of force to sustain the isometric contraction (Potvin, 2014). This can lead to muscle fatigue, decreased joint mobility, and increased musculoskeletal joint loading causing discomfort, impingement, and eventually, injury (McGinnis, 2013; Potvin, 2014).

Several studies have documented the link between static and/or awkward postures and injury. Bernard et al. (1997) summarized eight epidemiological studies examining the relationship between workplace factors (i.e., posture, repetition, force, and duration) and hand/wrist tendinitis. These studies reported evidence of positive associations of wrist tendinitis with any single or combination of workplace factors, with five of the studies reporting statistical evidence for a positive association with extreme postures (Bernard et al., 1997). Da Costa and Vieira (2010) reported similar evidence for the development of elbow/forearm and wrist/hand work-related musculoskeletal disorders (WMSDs). Twenty-two out of 63 epidemiological studies reported statistical evidence of a positive relationship between WMSDs and awkward postures in the upper limb, specifically for the elbow/forearm and wrist/hand. Callaghan and McGill (2001) conducted a study with eight male university students in sitting and standing postures to determine which posture produced greater compressive low back loads over time. Each participant was instrumented with EMG electrodes on various trunk flexor and extensor muscles and the lumbar flexion/extension angle was monitored between the sacrum and T11/T12 spinal segments. The authors reported a significant increase in compressive low back forces in sitting postures versus standing ($p < 0.001$) with an average of 500 N more force occurring in sitting due to the increased muscle activation of the lumbar extensors in a seated posture. They also concluded that non-neutral spinal postures can result in increased isometric contractions, especially over long periods of time. These studies, and many others, demonstrate that static and/or awkward postures are a risk factor for injuries acquired during occupational and daily living activities.

Drummers can experience static and awkward postures while sitting, reaching, and striking the drum set with force for long periods of time (Sandell et al. 2009; Cuden et al., 2015; Hawkins et al., 2015; Roseiro et al. 2018; Azar, 2020). Cuden et al. (2015) used the Rapid Upper Limb Assessment (RULA; McAtamney & Corlett, 1993) tool to establish guidelines for drum set component placement to promote neutral upper limb postures of Filipino drummers. The RULA scores corresponding to the most neutral postures for the upper limb were used to establish a 'green zone', which they defined as a location within the reach envelope where the RULA Upper Arm and Lower Arm Scores are +1 and +2, respectively (McAtamney & Corlett, 1993; Cuden et al., 2015). This green zone was split into three categories using mathematical equations, strike frequency, and RULA to find the acceptable reaching distances for the upper and lower arm (Cuden et al., 2015). This study showed a potential mathematical solution to positioning the drum set to the participant's preferred anthropometrics, strike frequency, and the RULA posture tool. The combination of these tools would help reduce stress and strain while performing the drum set by placing the highest strike frequency equipment closer to the throne to reduce non-neutral arm postures (Cuden et al., 2015). Recently, Flammia and Azar (2021) conducted a study using the Xsens MVN Awinda™ motion capture system on nine male drummers to describe the three-dimensional movement patterns of the wrist, elbow, and shoulder joints. The results showed that participants spent most of their playing time with their wrists extended (right: 95 %, left: 96.5 %) and outside of the neutral range (± 5°; right: 90.0 %, left: 90.1 %). They also analyzed wrist radial/ulnar deviation range of motion (ROM) (right: 95.1 ± 16.8°, left: 87.8 ± 19.0°) and percent time spent outside of the neutral range (± 5°; right: 73.4 %, left: 79.4 %). The authors concluded that extensive repetition in these postures could lead to PRMD diagnoses such as tendinitis and carpal tunnel syndrome due to their wrist postures (i.e., flexion/extension and radial/ulnar deviation). Therefore, non-neutral postures are likely to be a risk factor for PRMDs in drummers.

To summarize, force, posture, and repetition are all physical risk factors for developing musculoskeletal injuries, individually and particularly when they occur in combination (Bernard et al., 1997; da Costa & Vieira, 2010). While these risk factors are important when considering upper limb injury (Armstrong et al., 1993; ISO 5349-1, 2001; Chaffin et al., 2006), vibration transmission is another potential physical risk factor that can be exacerbated by force, repetition, and posture (Bernard et al., 1997). Therefore, it is important to understand the risks associated with vibration exposure in addition to the above physical injury risk factors in drummers.

2.3.4 Hand-arm Vibration Exposure

Vibration is the oscillatory motion of bodies (Chaffin et al., 2006). Any object that has mass and elasticity is capable of vibration, which include powered machines, structures, and even the human body (Chaffin et al., 2006). These vibrations can refract periodically (harmonics) forming a sine wave or in randomized (irregular) vibrations (Chaffin et al., 2006). Vibration is transmitted through the body by touching the object that is creating the accelerating waves (e.g., a power tool). The hands, feet, and sacral regions of the body are the most common areas where vibration transmission occurs during work-related tasks and activities of daily living (ISO 5349-1, 2001).

Hand-arm vibration (HAV) is vibration that is transmitted from the palms and fingers through the forearm (Chaffin et al., 2006; ACGIH, 2019). HAV exposure is common in many occupational, athletic, and daily living activities, including playing the drums. For example, Kunimatsu and Pathak (2012) documented frequency-weighted RMS accelerations in mining operators through their use of power tools (jack hammers, coal drills, etc.). They reported frequency-weighted RMS accelerations of 0.5-2.3 m/s^2 over an 8-hour workday. Thrailkill et al. (2012) assessed a sulky accessory for a commercial walk-behind lawn mower and reported A(8)e values of 0.8 m/s^2 (X = anteroposterior), 1.0 m/s^2 (Y = mediolateral), and 1.3 m/s^2 (Z = superior/inferior) over a duration of 107 minutes. Amaro et al. (2019) performed a multiple-case study of HAV exposure in six athletes who completed 10 tennis strokes in one minute. The authors reported ranges of frequency-weighted RMS accelerations of 20.9 – 34.3 m/s^2 in the X axis (anteroposterior), 16.4 – 36.7 m/s^2 in the Y axis (mediolateral), and 20.0 – 33.7 m/s^2 in the Z axis (superior/inferior). Drummers are exposed to HAV through repetitive impacts of the drumsticks against the drums and cymbals, with average A(8)e values of 3.0 m/s^2 – 4.4 m/s^2 in MT drummers (Roseiro et al., 2018). With longer exposure to HAV through vibrating objects or repeated impacts, adverse effects are likely to occur.

2.3.4.1 Potential Adverse Effects of HAV Exposure

Vibration can cause direct and indirect biomechanical stress to the musculoskeletal, nervous, and vascular systems of the human body (Pujari et al., 2019). Tissue resonance occurs when a source of vibration shares the same natural frequency as the tissue (Wakeling et al., 2003; Chaffin et al., 2006). Vibrations can cause tissue resonance from direct contact to the source of the vibration (i.e., hand touching a power tool: Chaffin et al., 2006; Pujari et al., 2019). Indirect vibration occurs when the vibrations are transmitted further along the connecting tissues (i.e., bones, ligaments, muscles) from the location where the original vibration is applied (Pujari et al., 2019). An example would be vibration applied directly on the palm of the hand is transmitted to the radius and ulna at the wrist joint. As resonant frequencies pass through the tissue, the vibrations will refract against bone, muscle, ligaments, and nerves; each tissue is affected at different resonant frequencies (Chaffin et al., 2006). The larger the mass of a structure, the lower the resonant frequency will be (Marras & Karowski, 2006). For example, the resonant frequencies of large body tissues (i.e., quadricep muscles) lie in the range of 2-30 Hz (Chaffin et al., 2006) and the resonant frequency of the forearm musculoskeletal system is 150-200 Hz (Marras & Karowski, 2006). The amplitude of the waves diminishes as they travel away from the point of application, and this depends on two factors: (1) the expansion of a wave front (attenuation) and the dissipation of energy or dampening (i.e., the material or the tissue itself) (Amick & Gendreau, 2000). When a shock-type excitation impact travels through the body, multiple passive and active tissues can dampen the amplitude of the vibration (Gruber et al., 2014). This means that higher frequencies are attenuated closer to the contact of the shock-type excitation impact (i.e., while running, the heel fat pad, running shoe, ankle ligaments, calcaneus, and articular cartilage will dampen the initial high frequency impact of the foot to the ground) (Gruber et al., 2014). As the shock-type excitation impact travels further along the lower limb (i.e., achilles tendon, soleus, gastrocnemius, tibia, fibula, etc.), the amplitude of the vibration decreases and relies on active attenuation properties (i.e., eccentric muscle contractions, increased muscle activation, change in joint angles, and joint stiffness adjustments) to attenuate the lower frequency (Gruber et al., 2014). Therefore, the lower frequency shock-type excitation impact vibrations travel further than higher frequencies. As high frequencies (> 20 Hz) pass through the tissue, the peripheral nerves are affected (Chaffin et al., 2006). The vibration interferes with nerve cell signalling of the sensory and somesthetic (somatosensory) receptors from the cutaneous, musculotendinous, and articular structures (Chaffin et al., 2006). This message is then filled with the vibration sensation which erases the hand's natural response to tactile stimulation and creates numbness and residual resonance through the musculoskeletal tissue (Chaffin et al., 2006).

Individuals who are exposed to HAV for long periods of time can exhibit signs of hand-arm vibration syndrome (HAVS), which describes the numbness and tingling in the fingers, palms, wrists, and forearms that develop because of vibration applied to the musculoskeletal, vascular, and neurological tissues (Roseiro et al., 2018; ACGIH, 2019). HAV exposure can lead to serious injuries including carpal tunnel syndrome, Raynaud's phenomenon (white finger or 'blanching'), tendinitis, nerve damage, and weakness in muscle activation (ISO 5349-1 2001; ACGIH, 2019). HAV exposure can also lead to increased fatigue and decreased sensory output or tactility of the nerves serving the hand and arm (Radwin et al., 1989; Chaffin et al., 2006). Therefore, it is important to quantify vibration exposures during occupational tasks to determine whether there is an increased risk of injury.

2.3.4.2 Quantifying Vibration Exposure

The International Organization of Standards (ISO) and the American Conference of Governmental Industrial Hygienists (ACGIH) have created standards and guidelines to help researchers, workers, and health and safety advisors to understand how to quantify and regulate vibration exposure in working adults through the tools or environments they are exposed to. ISO Standards 5349-1 and 5349-2 (2001) and 8041-1 (2017) provide guidelines for the measurement device specifications, measurement/evaluation techniques, and definition of vibration exposure. HAV is measured using accelerometers placed between the vibrating tool and the contact point of the hand (ISO 5349-1, 2001). This is not possible with drumming; therefore, the accelerometer is placed at the head of the third metacarpal bone (ISO 5349-1, 2001). The accelerometers record data triaxially, so that accelerations are captured along the three coordinate axes (i.e., anterior/posterior, superior/inferior, and medial/lateral).

ISO 5349-1 (2001) describes the steps that must be taken to analyze the accelerometer signals properly. First, a one-third octave analysis must be applied to the accelerometer signal. This separates the signal into one-third octave bands with centre frequencies ranging from 6.3-1250 Hz. This range constitutes the primary frequency range, and the calculation of frequency-weighted RMS acceleration (a_{hw}) must include all one-third octave bands within this range. This is important because it allows control of signal noise above and below the target frequency spectrum (5-1500 Hz). The RMS amplitudes of the accelerations within each one-third octave band are then calculated, and pre-determined weighting factors are applied (see Appendix A). This is done by multiplying the RMS acceleration in each one-third octave band by its weighting factor, squaring the weighted RMS acceleration in each band, taking the sum of all the weighted RMS accelerations, and finally, calculating the root mean square to find the overall frequency weighted RMS acceleration (a_{hw}), according to the following equation:

$$a_{hw} = \sqrt{\sum_i (W_{hi} a_{hi})^2} \qquad \text{Eq. (1)}$$

where W_{hi} is the weighting factor for the *i* th one-third octave band (Appendix A), and a_{hi} is the RMS acceleration value for the *i* th one-third octave band (ISO 5349-1, 2001).

Up to this point, the frequency weighted RMS accelerations along each coordinate axis (i.e., X = anteroposterior, Y = mediolateral, Z = superior/inferior) are analyzed separately to quantify the acceleration signal acting on the hand in each direction. This is important because each direction can have different amplitudes affecting the hand, which can be equally detrimental. The frequency-weighted RMS accelerations in the X, Y, and Z axes are reported separately and then combined to calculate the vibration total value (a_{hv}). This is defined by taking the root-sum-of-squares of the three component values (X, Y, and Z):

$$a_{hv} = \sqrt{(a_{hwx}^2 + a_{hwy}^2 + a_{hwz}^2)} \qquad \text{Eq. (2)}$$

where a_{hwx}, a_{hwy}, a_{hwz} are the frequency-weighted RMS acceleration values for X, Y, and Z axes, respectively (ISO 5349-1, 2001). Finally, the daily vibration exposure eight-hour equivalent (i.e., the A(8)e) can be calculated according to the following equation:

$$A(8)e = a_{hv}\sqrt{\frac{T_e}{T_0}} \qquad \text{Eq. (3)}$$

where T_e is the total daily duration of exposure to the vibration a_{hv}, and T_0 is the reference duration of eight hours (28,800 seconds). The A(8)e value is then compared to the ACGIH Action Limit (AL: 2.5 m/s^2) and Threshold Limit Value (TLV: 5.0 m/s^2).

When reporting HAV exposure data, the following characteristics should be included within the report, in accordance with the ISO standards:

- A brief description of the person being evaluated
- The operations/activities in which the HAV exposure occurred
- Tools/workpieces involved
- Location and orientation of the transducers
- Individual single-axis frequency-weighted RMS accelerations measured
- Vibration total value for each operation
- Total daily duration for each operation
- Daily vibration exposure eight-hour equivalent

The ISO standard for documenting HAV exposure accounts for the frequency spectrum, acceleration magnitude (intensity), duration per day, and cumulative exposure (ISO 5349-1, 2001). These characteristics of vibration are known to influence the effects of human exposure to HAV in working conditions (ISO 5349-1, 2001). The American National Standards Institution (ANSI) described an A(8)e value of 2.5 m/s^2 as a “health risk threshold”, which produces abnormal signs and symptoms in the hands and arms of some exposed persons (ANSI, 2006; Waserman, 2008). The ACGIH adopted this threshold (2.5 m/s^2) as their Action Limit (AL), at which point they recommend that standards and regulations of equipment be set in place for protection of employees who experience vibration exposure at work over an 8-hour workday. The ACGIH Threshold Limit Value (TLV) indicates that individuals who participate in an 8-hour work period should not be exposed to A(8)e values greater than 5.0 m/s^2 in the upper limb, which is believed to be the maximum value a worker can endure before Stage One of the Stockholm Workshop Classification System for vibration-induced white finger syndrome occurs (i.e., Stage One: mild; occasional attacks affecting only the tips of one or more fingers: Gemne et al., 1987; ISO 5349-1, 2001; ACGIH, 2019). The ACGIH AL and TLV for HAV are visualized in Figure 4. These measurements are important for the employer using vibration tools. If a certain tool exposes a worker to accelerations greater than the AL, HAV protection measures must be incorporated (i.e., gloves, reducing vibration duration; ANSI, 2006; Wasserman, 2008). Only in extreme cases where the proper protection measures are in place should a worker reach the 5.0 m/s^2 TLV (ANSI, 2006; Wasserman, 2008). If the tool being used exposes the worker to HAV levels that exceed the ACGIH TLV of 5.0 m/s^2 over an 8-hour workday, the tool must be removed from the workplace, redesigned, and retested under the ISO standard guidelines (Wasermann, 2008). When and if the tool remains under 5.0 m/s^2 over an 8-hour workday, it can return to regular use (Wasermann, 2008; ACGIH, 2019).

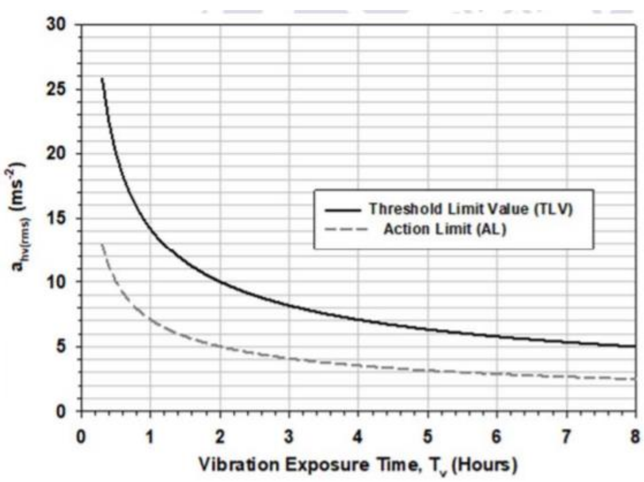

Figure 4. The vibration exposure TLV and AL as presented by the ANSI 2.70 (2006) and the ACGIH (2019). The dashed line represents the Action Limit (AL), and the solid line represents the Threshold Limit Value (TLV; Image taken from ACGIH, 2019, p. 1)

2.3.4.3 HAV Exposure in Drummers

Unfortunately, very little research has been conducted on HAV exposure in drummers. A pilot study by Roseiro et al. (2018) is the only research on this issue. Their study involved six male drummers who played basic drumming patterns for 180 seconds while accelerations were recorded from both hands. Roseiro et al. (2018) reported average A(8)e values of 3.0 m/s^2 and 4.4 m/s^2 in the left and right hands of MT drummers and 6.5 m/s^2 and 7.3 m/s^2, respectively, in NMT drummers. Higher frequency-weighted RMS accelerations were seen along the Y axis (i.e., medial/lateral) of all six individuals (Roseiro et al., 2018). The results suggested that the drummers could be at risk of HAV-related injuries based on the ACGIH AL (2.5 m/s^2) and TLV (5.0 m/s^2). Furthermore, the A(8)e values for NMT drummers approach the magnitude of the vibrations at which Radwin et al. (1989) observed tactile sensory decline (i.e., 8 m/s^2). Therefore, the evidence suggests that shock-type excitation impact HAV can pose a risk of developing vibration-related injuries from drumming.

While the study by Roseiro et al. (2018) is an important first step in documenting HAV exposure in drummers, the study design was limited in several important ways. First, they monitored HAV for only 180 seconds of drumming. Drummers reported playing for an average of 5-15 hours per week (Azar, 2020), and a live performance is can last between 25-161 minutes, often without breaks (Azar, 2021b). Therefore, a longer duration of HAV exposure should be recorded whilst playing the drum set for a more realistic representation. Secondly, the participants played an unspecified “musical piece”, which may not represent the complexity and diversity of musical pieces and the dynamics needed as a drummer. Finally, Roseiro et al. (2018) only included six participants in their study. Given the substantial proportion of drummers who experienced upper limb PRMDs (Azar, 2020), further investigation to document HAV exposure in drummers under realistic playing conditions is warranted.

CHAPTER 3: METHODS

3.1 Target Population

The target population for this study was professional, semi-professional, and serious amateur drummers 18 years of age or older. These individuals had at least two years' experience playing the drums and played the drum set for a minimum of five hours per week (Azar, 2020). Students enrolled in undergraduate or graduate music programs at a university or college, students taking private lessons, drum teachers, and studio or live performance drummers from all musical genres were eligible to participate. All participants were free of any ailments that limited their ability to play the drum set at the intensity and skill levels to which they were accustomed within the past 12 months. Individuals who primarily play other instruments, including other forms of percussion (e.g., timpani, marimba, drum line, etc.), or do not meet the above criteria, were excluded.

This study was originally conceived with a target of 20 participants to build on the findings of Roseiro et al. (2018). Due to the circumstances of the COVID-19 pandemic, a reduced number of six participants were recruited, and their data were analyzed using a case study approach. Although it was not possible to obtain a large sample size for this thesis, the literature can still be advanced by having the participants play the drums for longer periods and under more authentic and realistic playing conditions.

3.2 Participant Recruitment

Participants were recruited through the placement of posters in public places on the University of Windsor campus and in Windsor-Essex County (such as at music stores or music schools), email, and social media (i.e., Facebook, Twitter, and Instagram).

Interested parties contacted the investigators through email. The investigators screened them for inclusion/exclusion criteria, and they were briefed on the study procedures. Participants chose three songs that they performed during data collection and selected a data collection time slot. The participants were asked to wear comfortable clothes and to bring the in-ear monitors/headphones they normally use while playing with them to the data collection. They were also provided with a letter of information (Appendices B, C, and D) with the investigators' contact information containing further information about the study. The University of Windsor Research Ethics Board reviewed and cleared this study.

3.3 Instrumentation

3.3.1 Drum Equipment

Data collection proceeded using a standardized drum set (Figure 5). The drum set consisted of 8 pieces. The 12" and 14" rack toms, 16" floor tom, 14" snare drum, and 22" bass drum are a part of the Pearl Drums Decade Maple set. Each drum was covered with

Figure 5. Pearl Decade Maple drum set with Sabian XSR cymbals and Evans UV2 drumheads. Images used with permission from Dr. Nadia Azar.

Evans UV2 drumheads. The Sabian XSR cymbals included 14” hi-hats, 16” and 18” crash, and 20” ride and are made from pure Sabian B20 bronze metal.

A pair of drumsticks (Vater Los Angeles 5A Hickory; Holbrook, MA, USA; length: 40.4 cm, diameter: 1.5 cm, mass: 136.1 g) were provided by the investigator to standardize the drumsticks across all participants (Figure 6). The participants kept the drumsticks upon completion of the study.

Figure 6. A pair of Vater Los Angeles 5A hickory drumsticks. Image: Vater Percussion, Holbrook, MA, USA (used with permission). Retrieved from https://www.vater.com/#!/product/3.

3.3.2 Accelerometers

A triaxial integrated circuit piezoelectric (ICP) accelerometer was used to record accelerations (m/s^2) in the X, Y, and Z axes at the hand (SEN041F, PCB Piezotronics, Inc.; Provo, Utah, USA; Figure 7). The accelerometer’s dimensions were 10.2 mm x 19.6 mm x 10.2 mm, and its mass was 5.3 g (PCB Piezotronics, Inc., 2015a). The accelerometer was connected to the HVM100 Human Vibration Meter (PCB Piezotronics, Inc.; Provo, Utah, USA; Figure 8), which conditions and analyzes the accelerometer signals and displays the results on the unit’s screen. The HMV100’s dimensions were 8.3 cm x 15.2 cm x 2.5 cm and its mass was 279 g (PCB Piezotronics, Inc., 2015b). The accelerometer measurement range was ±500 g in all directions (PCB Piezotronics, Inc., 2015a). This measurement configuration and the on-board data

Figure 7. SEN041F accelerometer. Image used with permission from Dr. Nadia Azar.

Figure 8. The HVM100 Human Vibration Meter. Image used with permission from Dr. Nadia Azar.

analysis and processing met the requirements of ISO 8041:2005(E), ISO 5349-1:2001, and ISO 5349-2:2001 (PCB Piezotronics, Inc., 2015b).

Participants were instrumented with a single accelerometer, which was placed on the dorsal aspect of the hand at the third metacarpal head. The accelerometer was aligned with the biodynamic coordinate system, such that the z-axis was aligned with the longitudinal axis of the third metacarpal bone and the origin was at its head (ISO 5349-1, 2001: Figure 9). The accelerometer was secured to the hand using commercially available two-sided tape and reinforced with medical tape (i.e., Hypafix). The skin was cleansed with rubbing alcohol prior to application, to improve the adhesion of the two-sided and medical tapes. Self-adhesive flexible athletic tape was used to secure the accelerometer cables to the forearms and arms to minimize the cables' movements. A visual representation of the accelerometer placements can be seen in Figure 10. The HVM100 was placed on the participant’s belt loop with a clip to avoid interference while performing.

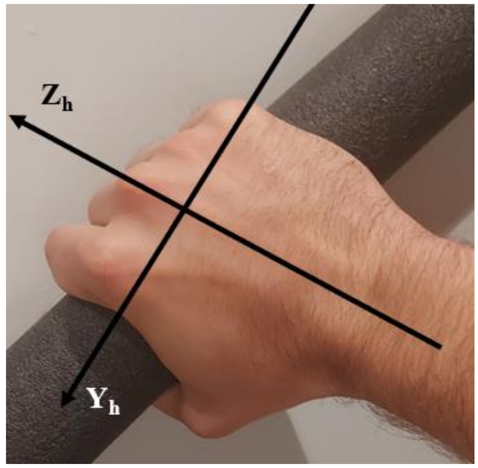

Figure 9. Coordinate system of the accelerometer relative to the dorsal aspect of the hand. The solid lines indicate the biodynamic coordinate system.

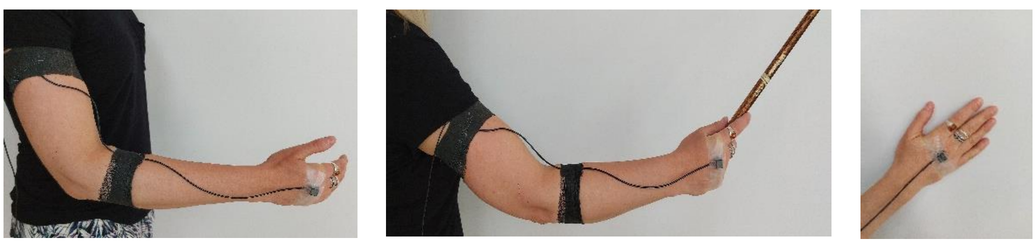

Figure 10. The accelerometer placement on the hands of the participant. Image used with permission from Dr. Nadia Azar.

3.3.3 Video Camera

The full duration of each song was video recorded using a Sony HandyCam® (sampling rate: 30 Hz) digital video camera. The recordings were made so that the accelerometer readings could be associated with specific features of the drummer’s performance, if or when necessary (i.e., cymbal crashes, striking the toms, striking the snare, etc.). This permitted an enhanced interpretation (if necessary) of the acceleration signals at specific points when the participant struck the drum set, but no quantitative video analyses were conducted.

3.3.4 Visual Analogue Scale

The Visual Analogue Scale (VAS) is a scale used to estimate a magnitude of a participant's perceived scale, the end points which describe the extreme points of the desired variable (i.e., pain, fatigue, etc.) (Carlsson, 1983). In this study, the VAS was used to measure participants' levels of fatigue after each set of three songs. The VAS for this study was a horizontal line that was 10 cm long, printed out on a sheet of paper (Figure 11). Participants used a pen to place a vertical mark on the line to represent their level of fatigue (ranging from 'no fatigue' on the left to 'completely fatigued' on the right). The distance of the vertical line from the left end of the VAS measured in centimetres to give a fatigue score ranging from zero to ten. The VAS is a valid and reliable measure to assess fatigue as it is easy to understand, and quick and simple to administer (Lee et. al, 1990).

3.4 Procedures

The data collection occurred at the biomechanics/ergonomics lab in the University of Windsor's Human Kinetics building (HK 242). On the day of the data collection, the participant was met at the front entrance and was led to the data collection room where the procedure was explained. The participants read and signed the informed consent

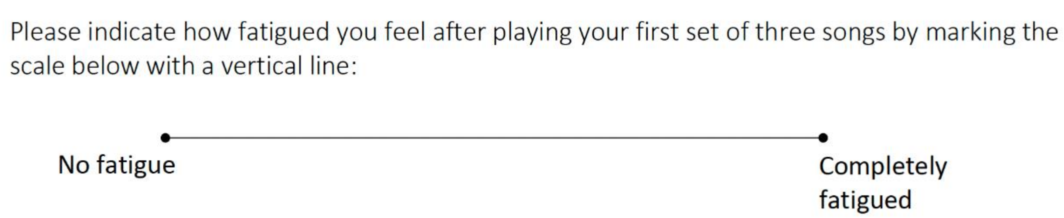

Figure 11. An example of the VAS used in this study.

form. They completed a short intake form (Appendix E) including questions about their playing history, injury history, typical genre of music, dominant hand, and equipment used (e.g., make/model of sticks, drum set, hearing protection, etc.).

The participants were instrumented with the accelerometer as described in Section 3.3.2, starting with the right hand. The participants were given 10 minutes to warm up and familiarize themselves with the drum set and with playing while instrumented. They were allowed to adjust the drum set to accommodate their personal anthropometrics and playing style. During this time, the investigators tested the accelerometer to ensure it was working properly. The investigators checked with the participants to ensure they felt comfortable with the equipment and any necessary adjustments were made.

Participants were asked to play a set of three songs (of their own choosing) with approximately 30 seconds of rest between songs while instrumented on the right hand. After the third song, the participants completed the first VAS, and then the accelerometer was moved to the left hand. The participants then repeated the same three songs in the same order. For both sets, the music was played through the participants' in-ear monitors or headphones, and the accelerometers and video recording device collected data continuously throughout each song, but the accelerometer was stopped between songs. After the final song, the video was stopped, the participants completed a second VAS, the accelerometer was removed, and the participants were free to leave. The participants were allowed to keep their set of drumsticks to ensure a brand-new set was used for each participant.

One of the six participants completed the study twice. Drummer D completed the same data collection as described above, however; at the second session the left hand was instrumented for the first set instead of the right hand. The songs were played in the same order as the first data collection. The purpose of this second data collection was to investigate any order effects that may have occurred when instrumenting the left hand first.

3.4 Data Processing and Analysis

3.4.1 Data Processing

The outcome variables for this study included the frequency-weighted RMS accelerations along the X, Y, and Z orthogonal axes (i.e., a_{hwx}, a_{hwy}, and a_{hwz}, respectively), the vibration total value (i.e., a_{hv}), the daily vibration exposure 8-hour equivalents (i.e., A(8) and A(8)e), and the participants' VAS scores. The A(8) was calculated using an exposure time equivalent to the duration of the three songs each participant played, whereas the A(8)e used the participants' self-reported daily playing time (e.g., 2-hour playing session) as the exposure time. Some participants provided a range of playing session time (i.e., 2-3-hour playing session). In these cases, the higher number within the range was used to calculate the A(8)e value. Therefore, the data were analyzed as a worst-case scenario. The vibration-related outcome variables were calculated in Microsoft Excel from the output of the HMV100 for each song individually and for all three songs combined, for each hand (respectively). The VAS scores were calculated for the first and second set of songs, respectively.

Percent differences between Drummer D's first (V_1) and second (V_2) sessions were calculated for each outcome variable, using the following equation:

$$C = \frac{V_1 - V_2}{\left(\frac{V_1 + V_2}{2}\right)} \; x \; 100 \qquad \text{Eq. (4)}$$

The percent differences for the overall outcome variables (i.e., calculated for all three songs combined) were used to examine the magnitude of the differences in the outcome variables when the left hand was instrumented first.

Occasionally, the HVM100 registered "over" readings within the time history of data. This indicated that the device had amplified the accelerometer signal to the point where it exceeded the range of the device's analog-to-digital converter, most likely due to the gain settings that were used (20 dB; Larson Davis Application Engineer, personal communication, May 24, 2022). This was found in three participants' data and did not happen frequently: Drummer A had one "over" reading out of 652 data points (0.15 %), Drummer B had 30 "over" readings out of 880 data points (3.4 %), and Drummer C had two "over" readings out of 806 data points (0.25 %). There were three instances where there were two "over" data points in a row found in Drummer B's data. Each "over" point was replaced with the average of the frequency weighted RMS acceleration time points immediately before and after the "over" data point.

3.4.2 Data Analyses

It was anticipated that each drummer would perform with different techniques, postures, skill levels, and musical genres. The drummers did not have any overlap in song choices. The data were analyzed using a case study approach to report each drummer's results separately and provided an in-depth analysis on their individual hand-arm vibration exposures. For every participant, vibration outcome variables were calculated for each song individually and for each hand, respectively, and then averaged across the three songs to get overall values for the left and right hand. Ranges and means of the outcome variables were also calculated across all participants. Individual and group A(8)e values were compared to the ACGIH (2019) AL and TLV for HAV over an eight-hour work period (2.5 m/s^2 and 5.0 m/s^2, respectively).

CHAPTER 4: RESULTS

Six adult male drummers (ages: 28 to 50 years) participated in this study. To protect the identities of the participants, only he/him pronouns will be used, and participants will be referred to as Drummer A-F. Appendix F provides the time histories of the vibration total value (a_{hv}) for each song played by each participant. The results are reported for the six participants separately (i.e., case study format), and group results are reported in the last section in this chapter. The results summary for Drummer D includes data from a second data collection session, which was conducted to investigate any differences in the data that may have occurred when instrumenting the left hand first.

4.1 Drummer A

4.1.1 Intake Summary

Drummer A is a 28-year-old male drummer who started playing the drums at 12 years of age. He has been a touring and session drummer for the last eight years as a rock genre drummer and has been teaching drum lessons for the last ten years and he is right-hand dominant. He has never had an injury that affected his ability to play the drums, and he underwent musical training for seven years. He plays an average of six hours/week in one-hour playing sessions, therefore his A(8)e was calculated using an exposure time of one hour. For this study, he played the following songs:

1. *Ain't It Fun*, Paramore (296 s)
2. *Falling For You*, Christee Palace (179 s)
3. *All I Can Do*, Buck Twenty (177 s)

4.1.2 Vibration and VAS Measurement Summary

Drummer A played for a total duration of 652 seconds in each set. He used a deadening ring (Big Fat Snare Drum, North Reading, MA, USA) for sound quality control during *Falling for You*. Table 2 lists the frequency-weighted RMS accelerations along the X, Y, and Z orthogonal axes (i.e., a_{hwx}, a_{hwy}, and a_{hwz}, respectively), the vibration total value (a_{hv}), the A(8), and the A(8)e for each song individually and for all three songs combined, for both the left and right hands. Figures F1-F3 (Appendix F) show the time histories of the vibration total value (a_{hv}) for each song. His A(8) values for the three songs combined were 3.3 m/s^2 on the right hand and 2.6 m/s^2 on the left hand. When extrapolating his exposure to his reported typical playing time of 1 hour, his A(8)e values were 7.6 m/s^2 on the right hand and 6.0 m/s^2 on the left hand, both of which exceeded the ACGIH (2019) AL (2.5 m/s^2) and TLV (5.0 m/s^2). Finally, Drummer A's VAS scores were 1.5/10 after the first set of three songs and 2.3/10 after the second set of three songs, indicating a low level of fatigue.

Table 2. Vibration-related outcome variables for Drummer A.

Song	Hand	a_{hwx} (m/s^2)	a_{hwy} (m/s^2)	a_{hwz} (m/s^2)	a_{hv} (m/s^2)	A(8) (m/s^2)	A(8)e (m/s^2)
Ain't It Fun	Right	12.0	16.6	12.6	24.0	2.4	8.5
	Left	7.0	9.6	16.9	20.6	2.1	7.3
Falling For You	Right	7.5	13.3	7.7	17.1	1.4	6.0
	Left	5.2	6.8	6.8	10.8	0.9	3.8
All I Can Do	Right	9.6	15.6	11.2	21.5	1.7	7.6
	Left	4.9	7.0	12.7	15.3	1.2	5.4
All Songs Combined	Right	10.3	15.5	11.1	21.6	3.3	7.6
	Left	6.0	8.2	13.6	17.0	2.6	6.0

4.2 Drummer B

4.2.1 Intake Summary

Drummer B is a 50-year-old male drummer who started playing the drums at 12 years of age. He has been a touring and session drummer for the last five or six years as a rock/metal genre drummer. He is right hand dominant and had carpal tunnel surgery on both hands 10 years ago. He reported that he has never had an injury that affected his ability to play the drums, and he is a self-taught, non-musically trained drummer. He plays an average of five to seven hours/week in two- to three-hour playing sessions, therefore his A(8)e was calculated using an exposure time of three hours. For this study, he played the following songs:

1. *Bangladesh*, Crawl (314 s)
2. *Heavy Rain*, Crawl (315 s)
3. *Snap Your Fingers*, *Snap Your Neck*, Prong (251 s)

4.2.2 Vibration and VAS Measurement Summary

Drummer B played for a total duration of 880 seconds in each set. Table 3 lists the frequency-weighted RMS accelerations along the X, Y, and Z orthogonal axes (i.e., a_{hwx}, a_{hwy}, and a_{hwz}, respectively), the vibration total value (a_{hv}), the A(8), and the A(8)e for each song individually and for all three songs combined, for both the left and right hands. Figures F4-F6 (Appendix F) show the time histories of the vibration total value (a_{hv}) for each song. His A(8) values for the three songs combined were 6.4 m/s^2 on the right hand and 4.8 m/s^2 on the left hand. When extrapolating his exposure to his reported typical playing time of three hours, his A(8)e values were 22.4 m/s^2 on the right hand and 17.2 m/s^2 on the left hand, both of which exceeded the ACGIH (2019) AL (2.5 m/s^2) and

Table 3. Vibration-related outcome variables for Drummer B.

Song	Hand	a_{hwx} (m/s^2)	a_{hwy} (m/s^2)	a_{hwz} (m/s^2)	a_{hv} (m/s^2)	A(8) (m/s^2)	A(8)e (m/s^2)
Bangladesh	Right	12.7	21.8	18.2	35.1	3.7	21.5
	Left	15.4	22.3	7.7	27.6	2.8	16.9
Heavy Rain	Right	21.1	22.6	19.2	36.1	3.8	22.1
	Left	11.1	16.8	15.3	25.3	2.6	15.5
Snap Your Fingers	Right	22.6	26.3	18.0	39.0	3.6	23.9
	Left	15.8	21.3	17.5	31.6	3.0	19.4
All Songs Combined	Right	21.4	23.4	18.5	36.6	6.4	22.4
	Left	14.1	20.1	14.1	28.1	4.8	17.2

TLV (5.0 m/s^2). Finally, Drummer B's VAS scores were 5.7/10 after the first set of three songs and 7.6/10 after the second set of three songs, indicating a moderate-high level of fatigue.

When observing the time history alignment with the Sony Handycam video recording, it was clear that the data from 286 – 316 seconds in the left hand during the first song (i.e., *Crawl – Bangladesh*) was recorded incorrectly. Drummer B was playing intensely with both hands from 286 – 316 seconds, but the a_{hv} time-history shows very low values in the left hand for the last 25 seconds of the song (see Figure F4, Appendix F). Drummer B mentioned at the end of this song that the accelerometer may have "slipped" or moved due to the perspiration whilst playing. The accelerometer was re-aligned with to the 3rd metacarpal head and taped into position, and the last 25 seconds was excluded from the outcome variable calculations for the left hand. The influence of this error on the outcome variables will be addressed in the Discussion section of this thesis.

4.3 Drummer C

4.3.1 Intake Summary

Drummer C is a 35-year-old male drummer who started playing the drums at seven years of age. He has been a hobby performing drummer for 15 years as a funk genre drummer. He is right hand dominant and uses standard stick grip style. He has never had an injury that affected his ability to play the drums and has had five years of formal drumming training. He plays an average of five to ten hours/week in one-hour playing sessions, therefore his A(8)e was calculated using an exposure time of one hour. For this study, he played the following songs:

1. *Hard Times*, John Legend ft. The Roots (316 s)
2. *Rock Steady*, Aretha Franklin (193 s)
3. *Stockholm Syndrome*, MUSE (297 s)

4.3.2 Vibration and VAS Measurement Summary

Drummer C played for a total duration of 806 seconds in each set. Table 4 lists the frequency-weighted RMS accelerations along the X, Y, and Z orthogonal axes (i.e.,

Table 4. Vibration-related outcome variables for Drummer C.

Song	Hand	a_{hwx} (m/s^2)	a_{hwy} (m/s^2)	a_{hwz} (m/s^2)	a_{hv} (m/s^2)	A(8) (m/s^2)	A(8)e (m/s^2)
Hard Times	Right	18.0	17.3	7.3	25.9	2.7	9.2
	Left	8.3	12.8	9.2	17.8	1.9	6.3
Rock Steady	Right	14.1	15.9	7.2	22.4	1.8	7.9
	Left	6.7	11.2	7.9	15.2	1.3	5.4
Stockholm Syndrome	Right	16.5	16.3	10.5	25.3	2.6	9.0
	Left	12.8	22.5	9.2	27.4	2.8	9.7
All Songs Combined	Right	16.6	16.6	8.6	24.9	4.2	8.8
	Left	10.0	16.8	8.9	21.3	3.6	7.5

a_{hwx}, a_{hwy}, and a_{hwz}, respectively), the vibration total value (a_{hv}), the A(8), and the A(8)e for each song individually and for all three songs combined, for both the left and right hands. Figures F7-F9 (Appendix F) show the time histories of the vibration total value (a_{hv}) for each song. His A(8) values for the three songs combined were 4.2 m/s^2 on the right hand and 3.6 m/s^2 on the left hand. When extrapolating his exposure to his reported typical playing time of 1 hour, his A(8)e values were 8.8 m/s^2 on the right hand and 7.5 m/s^2 on the left hand, both of which exceeded the ACGIH (2019) AL (2.5 m/s^2) and TLV (5.0 m/s^2). Finally, Drummer C's VAS scores were 0.9/10 after the first set of three songs and 2.0/10 after the second set of three songs, indicating a low level of fatigue.

4.4 Drummer D

4.4.1 Intake Summary

Drummer D is a 30-year-old male drummer who started playing the drums at 12 years of age. He is a Jazz/Pop/Soul/R&B genre drummer, has been playing for 15 years, and has had 10 years of formal drumming lessons. He is right hand dominant and uses French grip style. He played 10 years for the Canadian forces and another five years as a civilian performer. He has never had an injury that affected his ability to play the drums. He plays an average of ten hours/week in two- to three-hour playing sessions, therefore his A(8)e was calculated using an exposure time of three hours. For this study, he played the following songs:

1. *Pocket Full Of Soul*, Tower of Power (209 s)
2. *Short Court Style*, Natalie Prass (223 s)
3. *Bounce Pt. 1*, Nate Smith (160 s)

Table 5. Vibration-related outcome variables for Drummer D – Session 1.

Song	Hand	a_{hwx} (m/s^2)	a_{hwy} (m/s^2)	a_{hwz} (m/s^2)	a_{hv} (m/s^2)	A(8) (m/s^2)	A(8)e (m/s^2)
Pocket Full Of Soul	Right	4.1	5.7	4.1	8.1	0.7	5.0
	Left	4.3	6.8	5.0	9.5	0.8	5.8
Short Court Style	Right	4.9	5.4	3.8	8.2	0.7	5.0
	Left	3.2	5.9	3.0	7.3	0.6	4.5
Bounce Pt. 1	Right	4.5	4.8	4.8	8.2	0.6	5.0
	Left	3.1	4.5	3.1	6.2	0.5	3.8
All Songs Combined	Right	4.5	5.4	4.2	8.2	1.2	5.0
	Left	3.6	5.9	3.9	7.9	1.1	4.8

4.4.2 Vibration and VAS Measurement Summary – Session 1

Drummer D played for a total duration of 592 seconds in each set. Table 5 lists the frequency-weighted RMS accelerations along the X, Y, and Z orthogonal axes (i.e., a_{hwx}, a_{hwy}, and a_{hwz}, respectively), the vibration total value (a_{hv}), the A(8), and the A(8)e for each song individually and for all three songs combined, for both the left and right hands. Figures F10-F12 (Appendix F) show the time histories of the vibration total value (a_{hv}) for each song. His A(8) for the three songs combined in the first session was 1.2 m/s^2 on the right hand and 1.1 m/s^2 on the left hand. When extrapolating his exposure to his reported typical playing time of 3 hours, his A(8)e values were 5.0 m/s^2 on the right hand and 4.8 m/s^2 on the left hand, both of which exceeded the ACGIH (2019) AL (2.5 m/s^2) and the right hand reached the TLV (5.0 m/s^2). Finally, Drummer D's VAS scores for both performances were 0/10 after the first set of three songs and 0/10 after the second set of three songs, indicating zero fatigue.

Table 6. Vibration-related outcome variables for Drummer D – Session 2.

Song	Hand	a_{hwx} (m/s^2)	a_{hwy} (m/s^2)	a_{hwz} (m/s^2)	a_{hv} (m/s^2)	A(8) (m/s^2)	A(8)e (m/s^2)
Pocket Full Of Soul	Right	4.0	7.9	3.0	9.3	0.8	5.7
	Left	5.4	6.6	5.0	9.8	0.8	6.0
Short Court Style	Right	4.5	8.0	3.0	9.6	0.9	5.9
	Left	4.1	5.6	3.3	7.7	0.7	4.7
Bounce Pt. 1	Right	4.2	8.1	3.8	10.0	0.7	6.1
	Left	3.9	4.5	3.3	6.8	0.5	4.2
All Songs Combined	Right	4.2	8.0	3.2	9.6	1.4	5.9
	Left	4.6	5.7	4.0	8.3	1.2	5.1

4.4.3 Vibration and VAS Measurement Summary – Session 2

Drummer D played for a total duration of 592 seconds in each set. Table 6 lists the frequency-weighted RMS accelerations along the X, Y, and Z orthogonal axes (i.e., a_{hwx}, a_{hwy}, and a_{hwz}, respectively), the vibration total value (a_{hv}), the A(8), and the A(8)e for each song individually and for all three songs combined, for both the left and right hands. Figures F13-F15 (Appendix F) show the time histories of the vibration total value (a_{hv}) for each song. His A(8) for the three songs combined in the second session was 1.4 m/s^2 on the right hand and 1.2 m/s^2 on the left hand. When extrapolating his exposure to his reported typical playing time of 3 hours, his A(8)e values were 5.9 m/s^2 on the right hand and 5.1 m/s^2 on the left hand, both of which exceeded the ACGIH (2019) AL (2.5 m/s^2) and the TLV (5.0 m/s^2). Finally, Drummer D's VAS scores for the second session were 0/10 after the first set of three songs and 0/10 after the second set of three songs, indicating zero fatigue.

Table 7. Percent differences (%) in vibration-related outcome variables for Drummer D between Sessions 1 and 2. Negative values indicate higher frequency-weighted RMS accelerations in session two vs. session one.

Song	Hand	a_{hwx}	a_{hwy}	a_{hwz}	a_{hv}	A(8)	A(8)e
Pocket Full Of Soul	Right	2.4	-32.4	31.0	-13.8	-12.3	-13.1
	Left	-22.7	3.0	0.0	-3.1	0.0	-3.4
Short Court Style	Right	8.5	-38.8	23.5	-15.7	-25.0	-16.5
	Left	24.7	5.2	-9.5	-5.3	-15.4	-4.3
Bounce Pt. 1	Right	6.9	-51.2	23.3	-19.8	-15.4	-19.8
	Left	-22.9	0.0	-6.3	-9.2	0.0	-10.0
All Songs Combined	Right	6.9	-38.8	27.0	-15.7	-15.4	-16.5
	Left	-24.4	3.4	-2.5	-4.9	-8.7	-6.1

4.4.4 Vibration and VAS Measurement Summary – Session 1 and 2 Comparison

Table 7 lists the percent differences between sessions for each outcome variable except for VAS scores, as Drummer D reported VAS scores of 0/10 after both sets of songs in both sessions. For all three songs combined, the right hand registered larger a_{hwy} and a_{hv} magnitudes in the second session compared to the first (differences of -38.8 % and -15.7 %, respectively), and a larger a_{hwy} magnitude in the first session compared to the second (27.0 %). This resulted in substantial between-session differences in A(8) (-15.4 %) and A(8)e (-16.5 %). The left-hand registered a larger a_{hwx} magnitude in the second session (-24.4%), but the between-session differences in the other variables were minimal (i.e., less than 5 %), resulting in smaller between-session differences in A(8) and A(8)e (-8.7 % and -6.1 %, respectively).

4.5 Drummer E

4.5.1 Intake Summary

Drummer E is a 48-year-old male drummer who started playing the drums at 10 years of age. He has been a hobby performing drummer as a Funk/Pop/Rock genre drummer, playing for 25 years professionally, and has had 20 years of formal drumming lessons. He is right hand dominant and uses matched, closed grip style. He has toured and recorded music for 25 years. He has never had an injury that affected his ability to play the drums. He plays an average of 15-20 hours/week in two- to three-hour playing sessions., therefore his A(8)e was calculated using an exposure time of three hours. For this study, he played the following songs:

1. *Funky Miracle*, The Meters (147 s)
2. *Pick Up The Pieces*, Average White Band (239 s)
3. *Superstition*, Stevie Wonder (266 s)

Table 8. Vibration-related outcome variables for Drummer E.

Song	Hand	a_{hwx} (m/s²)	a_{hwy} (m/s²)	a_{hwz} (m/s²)	a_{hv} (m/s²)	A(8) (m/s²)	A(8)e (m/s²)
Funky Miracle	Right	5.5	6.4	3.6	9.1	0.7	5.6
	Left	3.6	6.3	2.6	7.7	0.6	4.7
Pick Up The Pieces	Right	4.7	5.9	3.1	8.1	0.7	5.0
	Left	4.1	6.8	3.0	8.5	0.8	5.2
Superstition	Right	4.8	5.6	3.1	7.9	0.8	4.9
	Left	3.6	5.9	3.0	7.5	0.7	4.6
All Songs Combined	Right	4.9	5.9	3.2	8.3	1.2	5.0
	Left	3.8	6.3	2.9	7.9	1.2	4.8

4.5.2 Vibration and VAS Measurement Summary

Drummer E played for a total duration of 652 seconds in each set. Table 8 lists the frequency-weighted RMS accelerations along the X, Y, and Z orthogonal axes (i.e., a_{hwx}, a_{hwy}, and a_{hwz}, respectively), the vibration total value (a_{hv}), the A(8), and the A(8)e for each song individually and for all three songs combined, for both the left and right hands. Figures F16-F18 (Appendix F) show the time histories of the vibration total value (a_{hv}) for each song. His A(8) for the three songs combined in the first performance was 1.2 m/s^2 on the right hand and 1.2 m/s^2 on the left hand. When extrapolating his exposure to his reported typical playing time of 3 hours, his A(8)e values were 5.0 m/s^2 on the right hand and 4.8 m/s^2 on the left hand, both of which exceeded the ACGIH (2019) AL (2.5 m/s^2) with only the right hand exceeding the TLV (5.0 m/s^2). Finally, Drummer E's VAS scores for both performances were 1.6/10 after the first set of three songs and 2.9/10 after the second set of three songs, indicating a low level of fatigue.

4.6 Drummer F

4.6.1 Intake Summary

Drummer F is a 32-year-old male drummer who started playing the drums at 11 years of age. He is as a Rock genre drummer, playing for 20 years, and has had five years of formal drumming lessons. He is right hand dominant and uses matched grip style. He has been a teacher for 15 years, gigging musician for 13 years, and has toured North America causally for three years. He had back pain with sitting while playing 4 years ago. He plays an average of 10-15 hours/week in 1.5-hour to 2.5-hour playing sessions, therefore his A(8)e was calculated using an exposure time of two and a half hours. For this study, he played the following songs:

a. *The Changeling*, The Doors (259 s)

b. *Whatcha Trying To Hand Me*, Jody Raffoul (222 s)

c. *Ghost of Rock N' Roll*, South River Sum (221 s)

4.6.2 Vibration and VAS Measurement Summary

Drummer F played for a total duration of 702 seconds in each set. Table 9 lists the frequency-weighted RMS accelerations along the X, Y, and Z orthogonal axes (i.e., a_{hwx}, a_{hwy}, and a_{hwz}, respectively), the vibration total value (a_{hv}), the A(8), and the A(8)e for each song individually and for all three songs combined, for both the left and right hands. Figures F19-F21 (Appendix F) show the time histories of the vibration total value (a_{hv}) for each song. His A(8) for the three songs combined in the first performance was 2.2 m/s^2 on the right hand and 2.3 m/s^2 on the left hand. When extrapolating his exposure to his reported typical playing time of 2.5 hours, his A(8)e values were 8.0 m/s^2 on the right hand and 8.3 m/s^2 on the left hand, both of which exceeded the ACGIH (2019) AL (2.5 m/s^2) and the TLV (5.0 m/s^2). Finally, Drummer F's VAS scores for both performances were 1.8/10 after the first set of three songs and 2.6/10 after the second set of three songs,

Table 9. Vibration-related outcome variables for Drummer F.

Song	Hand	a_{hwx} (m/s^2)	a_{hwy} (m/s^2)	a_{hwz} (m/s^2)	a_{hv} (m/s^2)	A(8) (m/s^2)	A(8)e (m/s^2)
The Changeling	Right	6.0	11.4	4.3	13.5	1.3	7.6
	Left	4.4	11.4	4.0	12.8	1.2	7.2
Whatcha Trying	Right	8.8	13.6	4.7	16.8	1.5	9.4
	Left	6.1	14.5	7.0	17.1	1.5	9.6
Ghost of Rock n' Roll	Right	5.8	10.3	4.0	12.4	1.1	7.0
	Left	5.6	12.4	5.9	14.8	1.3	8.3
All Songs Combined	Right	7.0	11.8	4.3	14.3	2.2	8.0
	Left	5.4	12.7	5.6	14.9	2.3	8.3

indicating a low level of fatigue.

4.7 Results Summary

Table 10 presents the means and standard deviations of the intake survey data (i.e., age, start age for playing the drums, weekly playing hours, average playing session duration, and average playing time per data collection session) across all six drummers. Table 11 presents the means and standard deviations for the outcome variables (all three songs combined) across all six participants. All six drummers reported using a closed hi-hat/snare pattern.

The highest overall a_{hv} values were observed in the right hand of five of the six participants (Drummer F recorded higher a_{hv} on the left). In both hands, the highest frequency-weighted RMS accelerations were observed in the Y axis (a_{hwy}) in five of the six drummers (Drummer C's highest RMS accelerations were in the X and Y axes for the right hand, while Drummer A recorded higher RMS accelerations in the Z axis for the left hand). When examining the group means, the drummers registered higher a_{hwx}, a_{hwy}, a_{hwz}, A(8), and A(8)e values in the right hand than in the left hand.

Figures 12 and 13 represent the A(8) and A(8)e (respectively) for all six participants individually and the group means for the right and left hands. Three of the six

Table 10. Summary of intake survey data across all participants. Values in brackets are the standard deviations.

Current age (years)	Average age of playing onset (years)	Average weekly playing time (hours)	Average duration of playing session (hours)	Average playing time during data collection (all three songs) (seconds)
38.8 (8.8)	10.7 (2.0)	11.3 (5.3)	2.3 (1.0)	714 (108.4)

Table 11. Summary of vibration and fatigue outcome variables across all participants. Values in brackets are standard deviations.

	a_{hwx} (m/s^2)	a_{hwy} (m/s^2)	a_{hwz} (m/s^2)	a_{hv} (m/s^2)	A(8) (m/s^2)	A(8)e (m/s^2)	VAS (no units)
Right Hand	10.8 (6.9)	13.1 (6.9)	8.3 (5.8)	19 (11)	3.1 (2.0)	6.7 (3.9)	1.9 (2.0)
Left Hand	7.1 (4.0)	11.6 (5.8)	8.1 (4.8)	16.1 (7.7)	2.6 (1.4)	5.7 (2.7)	2.9 (2.4)

drummers registered A(8) values exceeding the AL in both the right and left hands (Drummer A-C); however, all six participants registered A(8)e values that exceeded the AL in both the right and left hands. Four of the six participants (A, B, C, and F) registered A(8)e values that exceeded the TLV in both hands, while Drummers D and E met the TLV (5.0 m/s^2) in their right hands, but not their left hands. Finally, in observing the a_{hv} time-histories, all drummers recorded "choppier" or "jagged" a_{hv} traces in the left hand versus the right hand a_{hv} in each song.

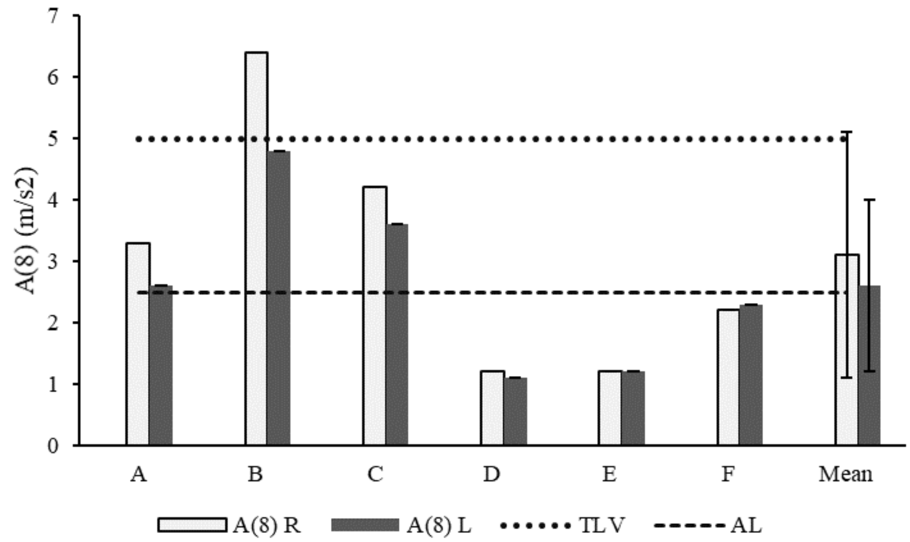

Figure 12. Daily vibration exposure equivalents A(8) in both hands for each participant individually and as a group (i.e., mean). The horizontal lines represent the ACGIH (2019) AL (dashed) and TLV (dotted) values, respectively.

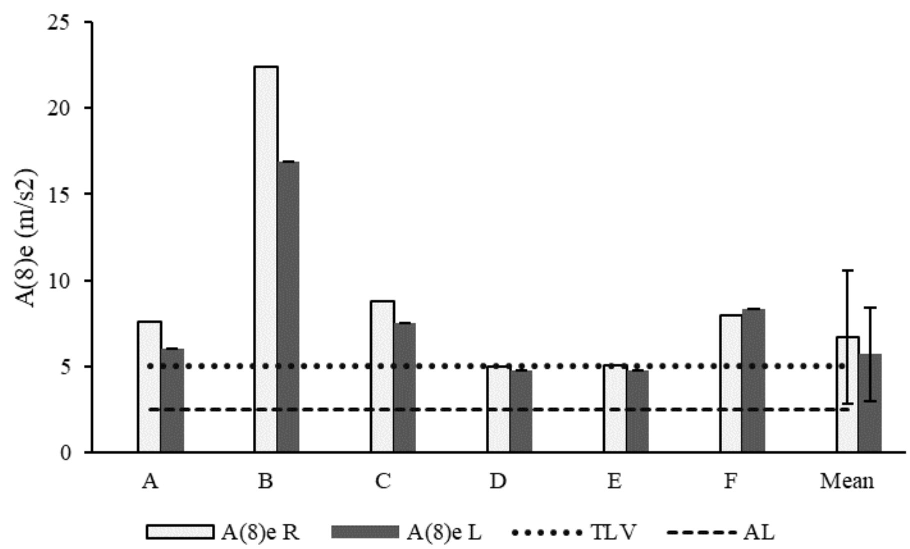

Figure 13. Extrapolated daily vibration exposure equivalents A(8)e in both hands for each participant individually and as a group (i.e., mean). The horizontal lines represent the ACGIH (2019) AL (dashed) and TLV (dotted) values, respectively.

CHAPTER 5: DISCUSSION

5.1 Overview

The purpose of this study was to examine HAV exposure in drummers through realistic playing scenarios and compare daily vibration exposure 8-hour equivalents (i.e., the A(8)e and the A(8)) to the ACGIH (2019) AL and TLV for vibration exposure. When extrapolating the participants' a_{hv} values based on their self-reported typical playing session time, all six participants' A(8)e values supported the hypothesis that drummers would exceed the AL in both hands, and results from four of the six drummers supported the hypothesis that they would exceed the TLV in both hands. Drummers D and E did not exceed the TLV in their left hands, but they came very close to meeting it (i.e., both registered A(8)e values of 4.8 m/s^2) in their left hands, and both of them met the TLV in their right hands (i.e., A(8)e values of 5.0 m/s^2). The average A(8)e across all six drummers was 5.7 m/s^2 in the left hand and 6.7 m/s^2 in the right hand. The drummers played for an average of 11.9 minutes (714 seconds) per hand during data collection, and the time used to calculate the A(8)e ranged from 1-3 hours. Five of the six drummers in this study were musically trained (MT). By comparison, Roseiro et al. (2018) reported an average A(8)e value of 3.0 m/s^2 in the left hand and 4.4 m/s^2 in the right hand in three MT drummers, and 6.3 m/s^2 in the left hand and 7.3 m/s^2 in the right hand of three non-musically trained (NMT) drummers who played for a total of 180 seconds. They used a playing session duration of two hours (7600 seconds) to extrapolate the a_{hv} for the non-musically trained (NMT) drummers, and a duration of four hours (14400 seconds) for the MT participants. This study expanded on the study by Roseiro et al. (2018) by collecting data over longer durations (i.e., average playing time of 11.9 minutes vs. 3 minutes), extrapolating the a_{hv} to the participants' self-reported typical daily playing session durations, and having participants play their specific genre of songs. This study's data showed higher A(8)e in all six participants compared to Roseiro et al. (2018), even though Roseiro et al. (2018) used a longer extrapolation time of four hours for their MT participants. This is likely due to the more realistic playing scenarios from increased playing session length and genre/song variation. Therefore, it is suggested that HAV exposure in drummers should be evaluated under the most realistic playing conditions possible to get the most valid hand acceleration measurements.

The group mean a_{hv} in this study exceeded the a_{hv} values reported by Kunimatsu and Pathak (2012) for mining operators using jack hammers (i.e., left hand: 16.1 ± 7.7 m/s^2, right hand: 19.0 ± 11.0 m/s^2 in the present study compared to the range of 0.5 – 2.3 m/s^2 of the tool vibration). Similarly, the group mean A(8)e values in each axis exceeded the A(8)e reported by Thrailkill et al. (2012) for participants using a sulky accessory for lawn mowers (i.e., 5.4 m/s^2 in anteroposterior [X], 6.6 m/s^2 in mediolateral [Y], and 4.2 m/s^2 in superior/inferior [Z] in the right hand; 3.6 m/s^2 in X, 5.9 m/s^2 in Y, and 4.0 m/s^2 in Z in the left hand of this study compared to 0.8 m/s^2 in X, 1.0 m/s^2 in Y, and 1.3 m/s^2 in superior/inferior (Z) axes reported by Thrailkill et al., 2012). However, the group mean A(8) values (i.e., 3.1 m/s^2 right hand, 2.6 m/s^2 left hand) were lower than the mean A(8) reported by Amaro et al. (2019) for six tennis athletes (i.e., 5.2 m/s^2). Only Drummer B recorded A(8) values that were comparable in magnitude to the tennis athletes (i.e., 6.4 m/s^2 right hand; 4.9 m/s^2 left hand). Overall, the data from this study suggests that drummers are exposed to HAV at levels comparable to those reported for industrial jobs and tennis athletes, and at levels that may put them at an increased risk of injury due to HAV.

While examining the A(8) values (i.e., the daily vibration exposure eight-hour equivalent based on the duration of the participants' data collection sessions), it was observed that three of the six participants exceeded the AL in both hands during the data collection session alone (i.e., without extrapolating the data based on their daily playing time). Drummer B even exceeded the TLV in the right hand (i.e., 6.4 m/s^2) and came close to meeting the TLV in the left hand (i.e., 4.9 m/s^2). These three participants played rock, metal, funk, or pop genre styles. Drummer D is a jazz genre drummer, and he recorded lower A(8) values than the other participants in both hands. It was also observed during data collection, and upon further review of the videos, that Drummers D and E played lower volumes, they appeared to grip the drumsticks more loosely, and hit the drum set from lower heights (i.e., less drumstick displacement) throughout their performances. This may be due to genre of music they were playing (i.e., jazz, funk) and their level of musical training compared to the other participants who played rock, metal, and pop genres. Drummer F, who played rock genre music, did not exceed the AL and TLV, where Drummer A (who also played rock/pop) exceeded the AL. Similarly, this may be due to the differences in song choices within the musical genres, as well as their musical training and/or grip technique. In the intake survey, Drummer A reported having taught lessons for ten years and touring as a session drummer for eight years, while Drummer F has been a drumming teacher for 15 years, gigging musician for 13 years, and has played the drums for 20 years total. This may relate to Drummer F having more musical training/experience, therefore, his experience may reduce the HAV whilst playing. Three out of six participants exceeded the AL and TLV during their playing session alone without extrapolating the A(8) to their respective playing times. This demonstrates the substantial amount of HAV these drummers experience in an average of 11.9 minutes of playing time, let alone the 2.3-hour average playing sessions that the participants reported playing outside of this study.

While examining the a_{hv} time history graphs of all participants, the time histories for the left hand were observed to be "choppier" or "jagged" in comparison to the time histories for the right hands. All six of the participants reported being right hand dominant, therefore, utilizing their right hands more frequently (hi-hat and ride cymbals) and potentially with more force (crash cymbals). Through observation of each participant's video recording, it was clear that the right hand was used to help keep tempo on the hi-hat and ride cymbals more frequently than the left hand, which used the snare more often to keep the back beat. For example, during Drummer F's performance of "*South River Sum – Ghost of Rock n' Roll*", the left hand was used to strike the snare to keep the back beat (i.e., emphasized beats two and four) which can be seen from the 67 – 80 second point of the song and again from the 145 – 160 second period creating "choppier" or "jagged" peaks in the time history graph. The right hand was used to strike the hi-hat and ride cymbals more frequently, which created a consistent a_{hv} of approximately 12 m/s^2, while the lower-frequency but higher force contacts of the left hand created spikes from 15 m/s^2 while striking the snare to lower average accelerations on the down beat (i.e., emphasis on beats 1 and 3). Similar patterns were observed in all the participants.

The a_{hwy} was the highest frequency-weighted RMS acceleration in five of the six participants in both hands, except for Drummer A, who's highest in the left hand was the a_{hwz} and Drummer C who shared highest a_{hwx} and a_{hwy} values in all three songs in the right hand. This may be due to the grip style, joint angle of the wrist and elbow, and displacement of the stick to the drum set while striking. The increased a_{hwy} RMS acceleration can be explained due to the placement of the accelerometer on the 3rd metacarpal head and the position of the drummers' hands while playing. The standard grip position in a French match-style grip has the dorsal aspect of the hand facing in the sagittal plane, therefore, pointing the Y axis in the superior/inferior direction and moving in the sagittal plane of movement. Therefore, as the height of the stick and hand moves up and down to reach different pieces of the equipment and create intensity/force while striking the drum set, the Y axis is displaced more frequently, creating higher a_{hwy} frequency-weighted RMS accelerations. This can be observed during video playback in five of the six drummers (B-F) using a French style grip described above. While observing the left hand of Drummer A's video recording, it can be noted that his left palm faced downward, pointing the Z axis of the accelerometer (which records accelerations along the long axis of the hand) in the anterior/posterior direction, therefore, increasing the frequency-weighted accelerations a_{hwz} values due to the specific rim shot technique he employed, which displaced the stick anteriorly and posteriorly along the snare during "*Paramore – Ain't it Fun*" and "*Buck Twenty – All I Can Do*". In observing Drummer C's video recordings, it was noted that he used a combination of French and German grip styles throughout the performance, changing the position of the accelerometer throughout his performance. Drummer C performed three songs that were ride cymbal and rack tom dominant. Due to the position of Drummer C's cymbals/rack tom set up and song choice, the consistent switching between French and German grips was observed. Therefore, the shared higher a_{hwx} and a_{hwy} values represent his unique technique to help keep tempo and rhythm during all three songs.

Drummer B was an anomaly compared to the rest of the study participants. He was the only NMT drummer, and he was the only one who played metal/rock genre songs for all three songs. He also recorded the highest a_{hv}, A(8), and A(8)e values in both hands. This is consistent with the Roseiro et al. (2018) study as NMT drummers recorded higher a_{hv}, A(8), and A(8)e values than in MT drummers. The metal/rock genre is usually played at a high tempo and volume, which requires the drummer to strike the drum set with greater force and more frequently due to the fast-paced tempo. This may explain why his results are higher in comparison to the other drummers in this study, however, more data must be collected on NMT and rock/metal drummers to truly understand the differences in HAV exposures between musical genres and drummers who are musically trained vs. untrained. During Drummer B's second set (i.e., left hand recording) of the first song "*Crawl – Bangladesh*", the last 25 seconds showed a_{hv} values that were lower than expected based on the intensity of the song he was playing. This was confirmed with video review as the last 25 seconds showed Drummer B's left hand striking the drum set with substantial force on the crash cymbals for the entire duration. The lab was very humid on the day of Drummer B's data collection and his hands were perspiring, and at the end of the first song of the second set, the participant mentioned that he felt the accelerometer may have moved under the tape during those last 25 seconds. Therefore, it can be assumed that the accelerometer was not correctly secured to the hand during this period, therefore, yielding lower a_{hv} values during the last 25 seconds of the first song of the second set (left hand). The data for these last 25 seconds were not included in the calculations of the outcome variables for the left hand. However, this missing data would have affected the A(8) and A(8)e values for Drummer B and potentially even for the group means, as they may actually be higher than previously reported.

Drummer D participated in two data collection sessions, one week apart, to test whether there would be substantial differences in the outcome variables when the left hand was instrumented first instead of the right hand. Higher a_{hwy} values were recorded from his right hand in all three songs, as well as higher a_{hwx} values in the left hand in all three songs in the second session than in the first, and this is reflected in the large negative percent differences for these variables (-38.8 % and -24.4 %, respectively). He also recorded a higher a_{hvz} value in the first session than in the second (percent difference: 27.0 %). The percent difference of the A(8)e was larger for the right hand (-5.7 %) than the left hand (-6.1 %), and both values were larger in the second session in comparison to the first session. Several factors may have caused this, such as variations in participant performance, equipment set-up, drumhead tension, and length of time between sessions. While Drummer D is an experienced percussionist, it is unlikely that he would be able to play at the exact same intensity from one performance to another. Drummer D also recorded the lowest a_{hv} values of the six drummers, which meant that small absolute differences in frequency-weighted RMS accelerations translated into substantial percent differences. However, this analysis only included a single drummer, so further analysis into differences between using one accelerometer at a time instead of two (i.e., one for each hand) may be warranted to better understand the differences in the outcome variables that arise from instrumenting the hands in separate trials instead of concurrently. The participants' group average VAS scores increased slightly from the first (i.e., 1.9 ± 2.0) to the second performance (i.e., 2.9 ± 2.4), and Drummer D was the only participant reporting no change in VAS score between sets. This suggests the increase in fatigue level was minimal between the first and second sets and fatigue levels remained low overall. Therefore, fatigue was likely to contribute minimally to the differences in the outcome variables between the right and left hands. However, the percent differences in Drummer D's data suggest that future studies using this methodology should counterbalance instrumenting the right hand or left hand first, and/or have all participants attend two data collection sessions, to reduce the potential influence of fatigue and to quantify inter-session differences in the outcome variables.

Drummer A used a dampening ring from *Big Fat Drum Co.* over the snare drum to produce certain sounds through his performance of "*Christee Palace – Falling For You*". This dampening ring may have reduced the a_{hv} during that song in both hands, however, further analysis of the differences of dampening and drumhead tensions would be needed to draw this conclusion.

5.2 Limitations

All studies have limitations, and it is important to be transparent when interpreting the data and how each outcome of this study may have affected the results. First, the HVM100 was limited to only recording data once per second. A drummer can hit the drum set multiple times within one second (i.e., half, $1/4^{th}$, $1/8^{th}$, and $1/16^{th}$ notes). Logan Newhouse won the World's Fastest Drummer Competition in 2021 by recording 904 strikes per minute (approximately 15 strikes per second: World's Fastest Drummer, 2022). While the HVM100 took the average frequency-weighted RMS acceleration within each second, a higher sampling rate would be ideal to further investigate differences in RMS accelerations related to playing each strike to the drum set. However, the HVM100 meets the ISO 5349-1 and 5349-2 standards for measuring frequency-weighted RMS accelerations. Industrial power tools can vibrate at much higher frequencies than drumming due to their high rotations per minute (i.e., RPM) in percussive or rotating motors, yet the same standards are used to evaluate HAV exposure from these tools (ISO 5349-1, 2001). Therefore, while it would be interesting to evaluate each stroke individually in future studies, the HVM100 was an appropriate analysis tool to meet the goals of this study.

Another limitation is that only one accelerometer conforming to the ISO 5349-1, 5349-2, and 8041-1 standards was available to be used for this study. Thus, it was not possible to record data from both hands at once without sacrificing the accuracy of the HAV assessment based on the accelerometer data. While having to perform each song twice, the participants may have played slightly differently between the first and second sets. The protocol was standardized so that the participants' right hands would be instrumented first, which could mean that levels of fatigue may have influenced the magnitudes of the outcome variables recorded in the second set. All participants reported being right-hand dominant, which may also cause some concerns for fatigue in the left (non-dominant) hand. However, the participants were experienced drummers who reported playing for an average of 2.3 ± 1.0 hours per playing session, while the average set duration for this study was only 11.9 minutes. The average VAS fatigue scores suggested a "low" level of fatigue was present, which was unlikely to have had a substantial impact on this study. However, counterbalancing the participants should be done going forward, such that half of the participants play with the right hand instrumented first and the other half play with the left hand instrumented first.

The choice to use a case study approach limited the ability to generalize the data across the rest of the drummer population as only six participants were recruited. Due to the COVID-19 pandemic, the drum set could only be used every 72 hours to ensure proper sanitation, instead of potentially ruining the drum set and other equipment due to the application of harsh sanitizing chemicals. This limited the number of participants that could be included in the study while still being able to complete this thesis within a reasonable amount of time; this research had already been delayed by nearly 18 months before health and safety restrictions eased enough to allow face-to-face research with human participants to resume. However, this study was still able to build on the study by Roseiro et. al (2018) using more authentic playing conditions and increased playing durations. In addition, the data collection is ongoing.

The participants' playing could have been affected by their lack of familiarity with the equipment (i.e., drum set, sticks, drumheads, etc.), and reduced comfort while wearing the accelerometer. For example, the participants were all required to use the same 5A hickory drumsticks during data collection, but the participants may not use 5A hickory drumsticks in their own drumming practice. This may have affected their movements and their comfort while playing with these drumsticks. Similarly, while the participants were allowed to adjust the drum set to allow for comfort while playing, the lack of familiarity with the drum set and playing with an accelerometer taped to their hands (and cables to their arms) could have made playing awkward and reduced the naturalness of their movements. The tension of the drumheads was also not standardized across all participants – they were allowed to adjust the drumheads to their preferences. It is acknowledged that each of these factors could have affected the magnitudes of the outcome variables recorded. Further analysis of the effects of different drumhead tensions on HAV transmission is warranted.

Lastly, four of the six participants gave their self-reported typical playing session durations in a range (i.e., Drummer F reported 1.5 – 2.5 hour playing sessions). The choice to use the higher playing session time in the A(8)e calculations may have resulted in overestimates of these values compared to estimates based on the minimum or average reported playing time. However, the use of the higher end of the range provided the "worst-case scenario" for each participant's A(8)e. For example, Drummer D reported that his typical playing session duration ranged from two to three hours. When calculating the A(8)e based on the lower end of this range (7200 seconds), the A(8)e for his right hand was 4.1 m/s^2 and left hand was 3.9 m/s^2. Although these values are lower than the A(8)e values calculated using the higher end of the range (10,800 s: 5.0 m/s^2 on the right hand; 4.8 m/s^2 on the left hand), Drummer D still exceeded the ACGIH (2019) AL values set by the ACGIH, and concerns about the level of HAV exposure remain. Figure 14 depicts the four participants' A(8)e values based on the lower value of each drummer's reported range of typical playing session time. Overall, all four drummers still registered A(8)e values that were higher than the AL in both hands. Drummers B and F registered A(8)e values that were above the TLV in both hands, while Drummers D and E registered A(8)e values that were below the TLV (but above the AL). Therefore, the concern for HAV exposure remained even when the lower reported playing session times were used to calculate the A(8)e.

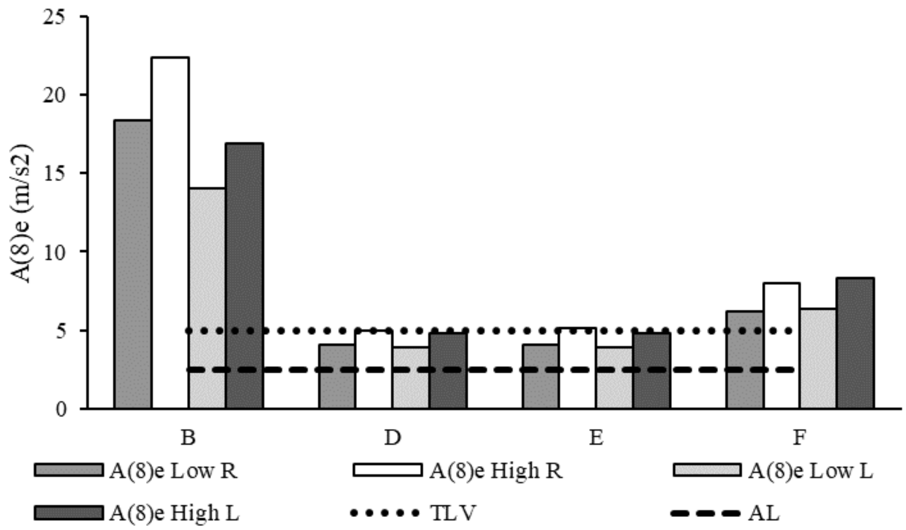

Figure 14. Comparison of four participants' extrapolated daily vibration exposure equivalents A(8)e in the left and right hands when calculated using both the low and high ends of the participants' self-reported ranges of typical playing session duration. All four drummers registered A(8)e values higher than the AL in both hands, regardless of extrapolation time. Drummers B and F registered A(8)e values higher than the TLV in both hands, while Drummers D and E registered A(8)e values lower than the TLV (but greater than the AL) in both hands.

5.3 Future Directions

The results of this study can be used as a basis upon which the research on HAV exposure in drummers can be expanded. Drummers may use a variety of different grip styles (e.g., matched vs. traditional grip), strike intensities (i.e., forte vs. piano in specific songs to create dynamics in musical pieces), playing techniques (e.g., Moeller technique, Alexander technique), play a variety of different musical genres (i.e., rock vs. metal vs. country, etc.), and use different drum equipment (e.g., drumstick materials, drumhead tensions, etc.). This study advanced the understanding of HAV exposure in drummers, but further work using larger sample sizes and addressing different research questions could provide insight into differences in HAV exposure related to musical genres, playing styles, drumming equipment, and the effects of musical training. While this study advanced the literature with the use of only one accelerometer on each hand, two accelerometers collecting simultaneously would allow researchers to investigate HAV exposures during longer performance durations and/or different song selections, and would reduce the chances that fatigue may lead to differences in the measured outcome variables between the two hands.

An increase in sample size would enable an examination of the effects of musical training (musically trained (MT) and non-musically trained (NMT) drummers) on HAV exposure. Roseiro et al. (2018) included three individuals who were NMT and the present study included one (Drummer B). In both studies, the NMT drummers registered higher a_{hv}, A(8), and A(8)e values than the MT drummers. However, the sample sizes are too small and there are too many other factors that would need to be accounted before a valid comparison could be made. If musical training is associated with lower HAV metrics, this would provide a strong rationale for engaging in musical training to promote better awareness and techniques for reducing vibration exposure.

As stated in the literature review, physical factors are not the only factors that likely contribute to the development of PRMDs in drummers. Monitoring HAV during live performances and band practices would enable further study of the effects of physical factors (i.e., strike force/intensity, posture, playing duration, fatigue, etc.), and would facilitate investigations regarding the impact of environmental factors (i.e., lighting, humidity, air quality, etc.), and psychosocial factors (i.e., crowd and band member interactions, anxiety/stress, etc.) on HAV exposure in even more realistic playing scenarios.

Further research could also examine differences in HAV exposure with different drumhead tensions and drumstick materials (i.e., hickory, maple, etc.). This could benefit drum equipment companies, as it would help them to understand which materials can cause increased vibration exposure so they can design sticks, drumheads, and cymbals to reduce vibration exposure whilst playing. Future studies could modify this study design to examine HAV exposure from specific drum equipment pieces (i.e., toms, snares, crash and ride cymbals, etc.). These data could also be used to analyze specific drum equipment to compare company designs, material usage, and qualities. Creating new alternatives or enhancements to existing equipment could reduce HAV exposures to within (or at least closer to) the ACGIH (2019) AL and TLV.

The data collection sessions for this study were all video recorded but quantitative video analysis was beyond the scope of this study. Video analysis could be used to investigate frequency-weighted RMS acceleration peaks to see which piece of the drum set/drumstick and/or technique was being used at the instant when the peak occurred. Therefore, further investigation into strike frequency and specific techniques (i.e., Moeller stroke, rimshots, snare vs. toms vs. cymbals, etc.) could be conducted to understand which pieces of equipment produce higher vibration magnitudes, and/or which playing techniques mitigate these peaks.

Vibration exposure may always be prevalent in drumming, even with advances in drum equipment technology. Therefore, the use of vibration damping gloves may be warranted when playing to reduce vibration transmission from the stick to the hands (ISO 5349-1, 2001; ACGIH, 2019). Future research could examine the effects of these gloves to understand how they may reduce HAV exposure in drummers.

Finally, it has been suggested that the pre-activation of a muscle can change the tissue length to increase vibration dampening of shock-type excitation frequencies greater than 40 Hz (known as active shock attenuation: Boyer and Nigg, 2007). In the lower limb, active shock attenuation can be enhanced through eccentric muscle loading, increased muscle activation, joint angles, and adjustments in joint stiffness through the feet while running (Perry, 1974; McMahon et al., 1987; Perry & Lafortune, 1995; Cole et al., 1996; Derrick et al., 1998; Wakeling et al., 2001; Boyer & Nigg, 2007; Gruber et al., 2014). Conversely, Burkhart and Andrews (2010) reported that with increased isometric contraction of the forearm muscles (i.e., flexor carpi ulnaris and extensor carpi ulnaris), the attenuation of vibration shock-like impacts at the wrist decreases. However, they also suggested that a certain level of isometric contraction could help attenuate axial (Z axis) accelerations in the elbow and shoulder joints by increasing joint stiffness, forcing optimal joint congruency at the elbow. Similarly, Sesto et al. (2006) stated that factors such as less joint stiffness, effective mass, and dampening of the upper limb in symptomatic industrial workers may result in less capacity to withstand the torques produced by power hand tools. Therefore, comparing HAV exposure under different eccentric loading, muscle activation, and joint angle conditions using EMG and motion capture data could enhance our understanding of whether these conditions are useful in attenuating shock-type excitation impacts in drummers. This could assist physical therapists and/or strength and conditioning specialists in developing exercise protocols specific to drummers to help them reduce injury risk due to HAV exposure.

CHAPTER 6: CONCLUSION

Overall, this preliminary analysis of HAV exposure in drummers suggests that further investigation of solutions to reduce HAV exposure in drummers is warranted. The drummers who participated in this study experienced an average A(8)e of 5.7 m/s^2 in the left hand and 6.7 m/s^2 in the right hand whilst performing in realistic playing scenarios, which exceeds the ACGIH AL (2.5 m/s^2) and TLV (5.0 m/s^2) values. Three of the six participants (A, B, and C) exceeded A(8) values higher than the AL and TLV safety standards during an average 11.9 minute playing session alone. Based on the results of this study, drummers can reach levels of HAV exposure that are similar to, or greater than, those reported in some industrial, occupational, and athletic settings. Further HAV exposure analyses with larger sample sizes and incorporating more realistic playing scenarios (i.e., live concert performances) across multiple musical genres and varying drummer skill levels would help to further advance our understanding of HAV during drumming. This additional information may enable the drumming community to develop new equipment, improve drumming technique/musical training, and understand how to use vibration mitigation techniques (e.g., gloves, muscle activation strategies) to reduce the risk of PRMDs associated with HAV exposure.

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APPENDICES

Appendix A: The frequency weighting factors to convert the one-third octave band magnitudes to frequency-weighted magnitudes. Reproduced from ISO 5349-1, 2001; p. 10.

Frequency Band Number (*i*)	**Nominal Mid Frequency (Hz)**	**Weighting Factor (W_{hi})**
6	4	0.375
7	5	0.545
8	6.3	0.727
9	8	0.873
10	10	0.958
11	12.5	0.951
12	16	0.896
13	20	0.782
14	25	0.647
15	31.5	0.519
16	40	0.411
17	50	0.324
18	63	0.256
19	80	0.202
20	100	0.160
21	125	0.127
22	160	0.101
23	200	0.0799
24	250	0.0634
25	315	0.0503
26	400	0.0398
27	500	0.0314
28	630	0.0245
29	800	0.0186
30	1000	0.0135
31	1250	0.00894
32	1600	0.00536
33	2000	0.00295

Appendix B: Informed Consent Form

CONSENT TO PARTICIPATE IN RESEARCH

Title of Study: ***Hand/Arm Vibration Exposure in Drummers***

You are asked to participate in a research study conducted by **Dylan Durward (graduate student) and Dr. Nadia Azar (faculty)**, from the **Department of Kinesiology** at the University of Windsor. **The results will contribute to Dylan's master's degree program.**

If you have any questions or concerns about the research, please feel to contact:

Dylan Durward, primary investigator:	durwardd@uwindsor.ca	
Dr. Nadia Azar, faculty supervisor:	azar5@uwindsor.ca	519-253-300 ext. 2473

PURPOSE OF THE STUDY

The goal of this study is to examine hand/arm vibration (HAV) exposure in drummers through realistic playing scenarios. This study will specifically examine vibration exposure (i.e., accelerations) at the hands. These accelerations will be compared to those documented for other professions and/or tools, and to the regulations set by the American Conference of Governmental Industrial Hygienists (ACGIH) for hand-arm vibration. The results of this study will provide a starting point to help others make research-based suggestions for improvements to drumming equipment (e.g., sticks, cymbals, drumheads, etc.), technique, and performance.

PROCEDURES

If you volunteer to participate in this study, you will be asked to do the following:

Prior to Meeting the Investigators:

- contact Dylan and/or Dr. Azar through email to ensure you fall within the inclusion/exclusion criteria
- notify Dylan/Dr. Azar of the songs you will play during data collection and select a mutually convenient data collection time slot
- Review this Informed Consent Form, the Consent for Still Photography and Audio/video Recording, and the Consent Addendum for COVID-19 Risks and Procedures for In-Person Research at the University of Windsor, and contact Dylan or Dr. Azar should you have any additional questions

On the Day of your Data Collection:

- complete the Safe Lancer App or the on-line fillable document within one hour prior to coming to campus and forward the results to the researcher (if you need instructions for downloading the app or the fillable form, please see the instructions on the last page of the *'Consent Addendum for COVID-19 Risks and Procedures for In-Person Research at the University of Windsor'*).
- meet the investigators at the front entrance of the University of Windsor's Human Kinetics building (2555 College Ave, Windsor, ON N9B 2Z5) wearing comfortable clothing. They will take you to room 242, where data collection will occur
- bring the headphones/in-ear monitors you normally use (if any)
- wear a 3-ply surgical mask and eye protection (e.g., safety glasses or face shield) at all times in while you are in the building. These will be provided to you unless you prefer to use your own.
- Wash and/or sanitize your hands upon entering and exiting the building, and at regular intervals while you are in the building
- complete a short intake questionnaire including questions about your demographic information (e.g., age, preferred gender pronouns, etc.), playing history, injury history, and performance style
- adjust the standardized drum kit provided so it feels comfortable for you to play
- be instrumented with an accelerometer (sensor to detect vibrations) on either your right or left hand
  - NOTE – removal of body hair in the areas where the accelerometer will be attached may be necessary, to make sure the device is firmly secured to the skin. In these cases, you will be provided with a disposable razor and asked to shave those areas. You can also choose to do so in the privacy of your own home prior to attending your data collection session.
- complete a brief warm-up (10 minutes) to ensure you are comfortable with the drum kit and accelerometer
- play a set of three songs (the ones you chose), presented in a random order, with approximately 30 seconds of rest in between songs. Music will be played through your own in-ear monitors or headphones
- play the same three songs in the same order with the accelerometer on the opposite hand
- give a rating of your level of fatigue after each set of three songs.

You will also be asked to:

- consent to the publication of the data and photos/videos in any, or all, of several forums. Examples include, but are not limited to:
    - Summary on the University of Windsor's Research Ethics Board website
    - Conference or other academic presentations (e.g., teaching, guest lectures, speaking engagements, etc.)
    - Academic publications (e.g., master's thesis document, peer-reviewed journals)
    - Online (e.g., investigator's website, online drumming communities, blogs and/or vlogs)
    - Summaries and/or case studies shared through social media (e.g., Facebook, Twitter, Instagram, etc.)
    - Articles in popular drumming magazines (e.g., Modern Drummer, Drum! Magazine, etc.)
    - Media appearances (e.g., radio, television, or online interviews such as podcasts, vlogs, and/or blogs)
    - Drummer Mechanics and Ergonomics Research Laboratory (DRUMMER Lab) promotional purposes (e.g., future study recruitment initiatives)

Publication in these forums can be achieved confidentially, if you wish. In those cases, no identifying information will be disclosed, and your face will be covered in any photos/videos (or, your photos/videos won't be used). **Please refer to the audio/video/still photography consent form at the end of this document to indicate your desired level of confidentiality.**

It is estimated that the process in the data collection room will take approximately two hours.

INCLUSION AND EXCLUSION CRITERIA

You ***can*** participate in this study if you:

- are 18 years of age or older
- are located in, or willing to travel to, the Windsor-Essex area (Human Kinetics Building at the University of Windsor. Travel expenses will not be reimbursed)
- have consistently played the drum set for an average of at least 5 hours a week for the past 2 years
- have been free from any kind of injury/ailments that affected your ability to play the drums to your accustomed level of proficiency and intensity for at least 12 months
- be fully vaccinated against COVID-19 (i.e., you have received two doses and the second dose was administered at least 2 weeks prior to your data collection)

You ***cannot*** participate in this study if you:

- are younger than 18 years of age
- are not located in/not willing to travel to Windsor-Essex County at your own expense
- do not have adequate experience on the drum kit
- are currently injured, or have suffered any injury/ailments that affected your ability to play the drums to your accustomed level of proficiency and intensity within the last 12 months
- are allergic to the ingredients in the adhesive tape used to secure the accelerometer
- are not fully vaccinated against COVID-19 (i.e., you have not received any doses, you have only received a single dose, or you have received both doses but the second dose was administered within the last 2 weeks)

POTENTIAL RISKS AND DISCOMFORTS

- As with any physical activity, there is a risk that you might develop muscular fatigue and/or soreness or a muscle or joint injury. The drumming you will do for this study will be similar in duration and intensity level to what you would typically experience in your own day-to-day playing, and so the risk of experiencing muscle fatigue/soreness or a muscle or joint injury is no different than the risk you take when playing on your own time. Any muscle soreness that might occur is expected to be mild and should subside within a few days.
- The adhesive tape used to secure the sensors and minimize the movement of the sensor cables may chafe or irritate the skin, or they may become uncomfortable if they are secured too tightly. This irritation is similar to that which may develop from the use of commercially available bandages and is expected to disappear within a few days. Care will be taken to secure the tape strips in such a way that the adhesive surfaces are comfortable when touching the skin. You are encouraged to let the investigators know if the tape is too tight or uncomfortable, or if it is irritating the skin (redness, rash, inflammation, etc.), so the tape can be adjusted or removed.
- The skin where the accelerometers will be placed might need to be shaved to improve the adhesion and facilitate the removal of the tapes. This could cause some skin irritation, similar to what you would experience with dry-shaving, and is expected to disappear within a few days.
- Due to the nature of the instrument, the volume in the data collection room will increase when you are playing. You will be required to wear your own in-ear monitors/headphones throughout the data collection.
- You may feel uncomfortable with the physical contact required during the application of the sensors and the tape strips. If you are uncomfortable with the application of the tape strips by Dylan or a member of the research team, you will be shown how to apply the tape yourself, and then it will be adjusted as necessary by Dylan or a member of the team when the sensors are applied.

- You may feel uncomfortable with the idea of shaving patches of hair on your arms. If you do not want these areas to be shaved, you can choose not to.
- You may feel uncomfortable disclosing the demographic information that is requested. This information is required to ensure the validity of the study and to ensure you meet all inclusion criteria. This information will remain confidential – it will only be tied to your randomized participant number, not your name. If you do not want to disclose this information you can choose to withdraw from the study.
- You may feel anxious or concerned about potential exposure to COVID-19 from your participation in this study. Research staff will follow multiple safety precautions, including wearing 3-ply surgical masks and eye protection, wearing gloves while we apply the accelerometers, routine and frequent handwashing and sanitizing, spacing data collections by at least 72 hours, and limiting breaches of physical distance to no more than 15 minutes in total. Your participation in this study is completely voluntary, and you are free to withdraw from the study at any time by following the procedures outlined below.
- Although the data collection will occur in a private room, it will occur in a public building, so you may be seen walking into the building by members of the public. If you are concerned about the possible loss of status, privacy, and/or reputation you can choose to withdraw from the study.

POTENTIAL BENEFITS TO PARTICIPANTS AND/OR TO SOCIETY

While we do not anticipate any direct benefits to the participants, you might benefit from knowing that you contributed to research in an emerging field (and, as a drummer yourself, one in which you have a vested interest). Your contributions will also help to benefit the drumming community and common interests of the investigators and participants. You may be educated on the research equipment, how to improve your playing posture, and/or how to engage in proper warm-up/cool-down and break-taking to reduce the risks of injury due to HAV exposure. The results of this study may provide important evidence for a mechanism of injury for drumming-related upper limb injuries such as tendinitis and carpal tunnel syndrome. This research will help provide a base of knowledge upon which recommendations for drummer posture, practice habits, technique, etc. can be followed to minimise the risk of developing musculoskeletal disorders while playing the drums. It may also lead to new considerations for drum equipment design. Finally, this research will help foster a relationship between the Department of Kinesiology and School of Creative Arts that will be built upon in the future.

COMPENSATION FOR PARTICIPATION

You will receive a Kinesiology Research t-shirt as a token of gratitude for your time You may also keep the pair of drumsticks you used during data collection.

CONFIDENTIALITY

Participant anonymity is not possible with this research as the data collection is required to occur in person, with you and the investigators and occasionally other members of the research team (i.e., other lab members who are there for training or to provide assistance) in the same room. However, only members of the research team will be present during data collection. Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission.

Data confidentiality will be handled as follows:

1. Accelerometer data and intake forms will be collected and stored in a de-identified manner (i.e., by participant code only). These data will also be disseminated in a de-identified manner unless you indicate that you consent to non-confidential dissemination on the last page of this informed consent form (i.e., the audio/video/still photography consent form).
2. All audio-visual files will be collected and stored in a de-identified manner (i.e., by participant code only). Video/photos will only be used for dissemination if you indicate your consent for partially confidential or non-confidential use of your photos/videos on the last page of this informed consent form (i.e., the audio/video/still photography consent form).
3. A file linking participant names to their participant codes will be encrypted, password protected, and stored on the investigators' password-protected computers and/or OneDrives.

Raw data are valuable for future studies, and therefore the data collected in this study will not be destroyed. Hard copies of the signed informed consent forms and the de-identified intake forms will be kept in a locked filing cabinet in the Biomechanics Lab and will be labelled with individualized participant codes until the conclusion of the study, when they will be moved to a locked filing cabinet in the faculty supervisor's office and stored indefinitely. The de-identified digital data and the photos/videos will be stored indefinitely on the investigators' password-protected computers and/or OneDrive. All data recorded will be labelled with the participants' unique identifying code and not their name. A document linking participants' names and unique identifying codes will be encrypted, password protected, and kept on the investigators' password-protected computers and/or OneDrives. At the end of the study, Dylan will surrender this file to Dr. Azar and will delete it from his computer. However, he will retain the right to keep a copy of the de-identified data and the photos/videos. Dr. Azar will keep the file linking participant names to their codes indefinitely (i.e., encrypted, password protected, and kept on a password-protected computer and/or OneDrive). The GlobalProtect Virtual Private Network (VPN) will be used on all computers that are used to access the data.

PARTICIPATION AND WITHDRAWAL

You will be able to withdraw from the study at any point up until two weeks following your date of data collection. After this two-week period, it will be assumed that you consent to the use of your data and photos/video recordings in any or all of the forums listed above.

If you want to withdraw from participation during the data collection period, you can let the research team know verbally and the study will be stopped immediately. If you decide you want to withdraw from the study after your data has been collected, you can contact Dylan Durward by email (durwardd@uwindsor.ca) within two weeks of the date of your data collection with your request to withdraw.

As soon as you withdraw from participation (either verbally or in writing within two weeks of the date of your data collection) your digital data (including photos/video recordings) will be promptly deleted from all electronic devices and databases and hard copies will be destroyed.

The investigators may withdraw you from this research if circumstances arise which warrant doing so. These circumstances may include, but are not limited to, the determination that you do not fall within the inclusion criteria.

All participants who schedule and show up to their assigned data collection time slot will receive and be welcome to keep a Kinesiology Research t-shirt and a pair of drumsticks as our token of gratitude for their time.

FEEDBACK OF THE RESULTS OF THIS STUDY TO THE PARTICIPANTS

A summary of the findings of this research will be made available to participants and the general public upon completion. It will be posted on the University of Windsor's research website (address below) and on Dr. Azar's social media pages.

Web address: https://scholar.uwindsor.ca/research-result-summaries/
Social Media Handle: @DrNadiaAzar (Facebook, Instagram, Twitter)
Date when results are available: December 31st, 2022

SUBSEQUENT USE OF DATA

These data may be used in subsequent studies, in publications, and in presentations, as described above and on Consent for Still Photography and Audio/video Recording form.

RIGHTS OF RESEARCH PARTICIPANTS

If you have questions regarding your rights as a research participant, contact: The Office of Research Ethics, University of Windsor, Windsor, Ontario, N9B 3P4; Telephone: 519-253-3000, ext. 3948; e-mail: ethics@uwindsor.ca

SIGNATURE OF RESEARCH PARTICIPANT/LEGAL REPRESENTATIVE

I understand the information provided for the study ***Hand/Arm Vibration (HAV) Exposure in Drummers*** as described herein. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

☐ I would like Dr. Nadia Azar to retain my contact information so that I can be contacted with information about the possibility to participate in future DRUMMER Lab research studies.

____
Name of Participant

____________________________________ __________________
Signature of Participant Date

SIGNATURE OF INVESTIGATOR

These are the terms under which I will conduct research.

____________________________________ __________________
Signature of Investigator Date

Appendix C: Audio/Visual Consent Form

University of Windsor

CONSENT FOR STILL PHOTOGRAPHY AND AUDIO/VIDEO RECORDING

Research Participant Name: ________________________________

Title of the Project: Hand/Arm Vibration Exposure in Drummers

This study will involve the use of still photography, video, and/or audio recording. I understand these are voluntary procedures and that I am free to withdraw at any time by requesting that the recording and/or photography be discontinued.

All recordings and photographs will be stored on password-protected computers and OneDrives.

I understand these recordings/photographs may be used for dissemination of the results of the study in any, or all, of several forums. Examples include, but are not limited to:

- Summary on the University of Windsor's Research Ethics Board website
- Conference or other academic presentations (e.g., teaching, guest lectures, speaking engagements, etc.)
- Academic publications (e.g., master's thesis document, peer-reviewed journals)
- Online (e.g., investigator's website, online drumming communities, blogs and/or vlogs)
- Summaries and/or case studies shared through social media (e.g., Facebook, Twitter, Instagram, etc.)
- Articles in popular drumming magazines (e.g., Modern Drummer, Drum! Magazine, etc.)
- Media appearances (e.g., radio, television, or online interviews such as podcasts, vlogs, and/or blogs)
- Drummer Mechanics and Ergonomics Research Laboratory (DRUMMER Lab) promotional purposes (e.g., future study recruitment initiatives)

I have indicated my level of consent to the use of audio/videotaping and/or photography of study procedures while wearing the research equipment, using the check boxes below:

☐ **Non-confidential use**: I give the investigators permission to use my likeness in the manners listed above without any masking, such that I will be fully identifiable in the photos/videos.

☐ **Partially confidential use**: I give the investigators permission to use my likeness in the manners listed above, provided that my face is masked. I understand that any visible tattoos or other markings may not be able to be masked, and so I may still be identifiable based on these features.

☐ **Fully confidential use only**: my videos and/or photos may only be viewed by the research team during data analyses. I do not wish for them to be used in any public presentations of the data.

This research has been cleared by the University of Windsor Research Ethics Board.

________________________________ ________________________

(Research Participant Signature) (Date)

Appendix D: COVID-19 Addendum

Consent Addendum for COVID-19 Risks and Procedures for In-Person Research at the University of Windsor

Title of Research Project: Hand/Arm Vibration (HAV) Exposure in Drummers

You have already been invited to participate in a research study conducted at the University of Windsor and have given your consent to participate. This additional consent form is intended to bring your attention to important information related to the COVID-19 pandemic and risks associated with in-person participation in research. This form also informs you about the strategies that researchers will implement in this project to modify their procedures in light of the pandemic.

Due to the current global COVID-19 pandemic, Canadian public health authorities have strongly recommended that everyone (especially high-risk individuals or those in contact with high-risk individuals) take additional precautions. The University of Windsor is attempting to limit the risk of exposure to COVID-19 by using reasonable efforts to follow the health and safety guidelines recommended by the federal, provincial and local health authorities (https://www.wechu.org/). Nevertheless, there remains a risk that by coming onto the University of Windsor campus or any of the University of Windsor study sites, you may contract the virus that causes COVID-19.

You are reminded that your participation in this research is voluntary and you can withdraw from the research per the terms as set out in the main consent agreement for this research. Please feel free to ask questions and express any concerns as you read through the information in this form by contacting the individuals noted in the main consent form. **If you are feeling unwell or experiencing any potential COVID-19 symptoms, please do not come to campus and notify a member of the study team that you cannot attend**. Contact information can be found on the consent form that has been shared with you.

In order to help reduce the risk of spreading COVID-19, the University of Windsor is following Public Health Ontario directions in addition to taking the following safety precautions:

What you will be asked to do:

- Complete the Safe Lancer Application or the on-line fillable document. On the day of your visit, no more than an hour before you come to campus, you must complete the Safe Lancer Application (https://www.uwindsor.ca/campuspolice/safelancer) or the on-line fillable document (https://www.uwindsor.ca/returntocampus/sites/uwindsor.ca.returntocampus/files/0042_rtc_questionnaire_safe_lancer_-_final.pdf). Once you have completed this activity, you must forward the results to the researcher prior to arriving on campus. If you do not receive a positive confirmation, please contact the research team to reschedule your appointment. For further instructions on how to use the on-line applications, please see below.
- Wear PPE while at the study site: Wear the mask, face shield, goggles or any other personal protective equipment (PPE) provided by the researchers during the entire time you are at the study site. The face covering provided to you should fully cover your mouth and nose.
- Provide information on your vaccination status, if asked. The research team may ask you for your vaccination status if this is part of their approved screening protocol. If they do ask, they will want to know if you have had both vaccinations and the date of your last shot.

What the researchers will do:

- Follow the guidance provided by the University of Windsor for conducting research on campus. All research team members will follow the University of Windsor COVID-19 Research and Innovation Guidance (**https://www.uwindsor.ca/vp-research/353/covid-19-research-and-innovation-guidance**).
- Wear PPE at all times during the data collection. All researchers and participants will be required to wear a 3-ply medical grade mask as well as a face shield or goggles if physical distancing cannot be maintained. These personal protective equipment (PPE) will be provided to you by the research team.
- Sanitize all surfaces. The research team will ensure that all surfaces and/or shared equipment will be sanitized between participants' appointments. The researchers will use disposable equipment as much as possible.
- Maintain physical distancing unless approved for close contact. All researchers and participants must maintain a physical distance between them of 2 metres or more, unless some study procedures require closer distance or contact (for example, taking saliva or blood samples), applying or fitting equipment, or other preparation for participation that requires close contact or touching. If 2 metres of distance is not possible, the study procedures will include additional safety measures that were approved by the University of Windsor's Research Safety Committee and cleared by the Research Ethics Board.

contact information may be shared with public health authorities for the purpose of contact tracing. Contact information will be stored securely and separately from research data. Your information for contact tracing will be destroyed as soon as permitted by public health authorities (usually after 14 days).

The Government of Canada provides information on COVID-19 risks and prevention and on taking care of your mental health during the COVID-19 pandemic.

You are asked to acknowledge and accept the information outlined above regarding the risks of COVID-19 exposure and the related safety measures that have been put in place. By signing this document, you confirm that you have read the information above and have had an opportunity to ask questions.

☐ I acknowledge (check box if all of the following are true)

- I have completed the Safe Lancer App or the on-line fillable document prior to coming to campus and have forwarded the results to the researcher (if you need instructions for downloading the app or the fillable form, please see the instructions below).
- I am not experiencing any potential Covid-19 symptoms (e.g., fever, cough, trouble breathing);
- In the last 14 days, I have not travelled outside Canada or had close contact with anyone who has any of the symptoms listed above or a confirmed or presumed case of COVID-19.

If requested:

☐ I acknowledge:

- I have received both vaccinations for COVID19
- My second vaccine was on (**DATE**): __________________

I understand the COVID-19 information including risks and mitigation strategies and their limitations provided for the study. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

____
Name of Participant

______________________________________ ___________________
Signature of Participant Date

Instructions for using the Safe Lancer App:
Within an hour before arriving to the research site:

Step 1: On the Safe Lancer App main page click the "COVID-19 Updates & Self-Assessment"
Step 2: Click "Self-Assessment Tool"
Step 3: Click "Start Self-Assessment". Read the questions carefully and answer "Yes" or "No" and click "Continue".
Step 4: Confirm answers and submit.
Step 5: Upon completion of the screening questions, you must show confirmation, of a green badge to enter the research site. Click on the QR code and send via email to the researcher's email listed on the consent form (To forward your badge, tap the QR code once. At the top of the badge screen, copy the URL link and paste it into an email to forward).

If you do not have a phone or tablet to download the Safe Lancer App:
On-line fillable self-assessment form:

- Within an hour before arriving to the research site, download the self-assessment questionnaire using the following link: https://www.uwindsor.ca/returntocampus/sites/uwindsor.ca.returntocampus/files/0042_rtc_questionnaire_safe_lancer_-_final.pdf
- Complete this form and e-mail it to the researcher using the address provided by the researcher.

Paper version of the self-assessment form:

- Ask the researcher for a hard copy of the self-assessment tool, which you'll have to complete immediately before coming onto campus, and then give the completed self-assessment paper to researcher when you arrive at the study site.

Appendix E: Intake Form

Participant Identification Number: ____________________________________
Date/time/location: ____

Date of Birth: ____
Sex: ____________________
Preferred Pronouns: ____________________
Allergic to latex, adhesives, etc? ____________________
Fully vaccinated against COVID 19? _________________
Date second dose was administered: __________________

Songs chosen for data collection:

Song Title	**Artist**
1.	
2.	
3.	

Performance Style

Main musical genre:	
Dominant hand:	**RIGHT / LEFT**
Common grip style(s) used:	
Do you play an open-handed or closed-handed hi-hat/snare pattern?	**OPEN / CLOSED**
Do you play a single or double bass drum pedal?	**SINGLE / DOUBLE**
How often do you change your drumsticks (i.e., start using a fresh pair)?	
Do you currently use any vibration mitigation strategies? Examples include wearing gloves, using stick wraps, dampers on your cymbals/drumheads, etc.	

Playing History

At what age did you start playing the drums?	
How long have you been playing the drums for at least 5 hours per week?	
How many hours do you play the drums per week?	
What is an average duration of a playing session (i.e., practice or performance)?	
Have you ever taken formal drum lessons?	**YES / NO**
If yes, for how long?	
Describe the extent of your drumming experience and career. For example, “touring drummer for 10 years, playing since the age of 7 years”.	

Injury History

Have you ever had an injury that interfered with your ability to play the drums at the skill and/or intensity levels to which you are accustomed? (any cause)	**YES / NO**
What part of the body did this injury affect?	
Approximately how long ago/When did this injury occur?	
Has this injury affected your ability to play the drums to the skill and/or intensity levels to which you are accustomed within the last 12 months?	

Appendix F: Participant Vibration (a_{hv}) Time-histories

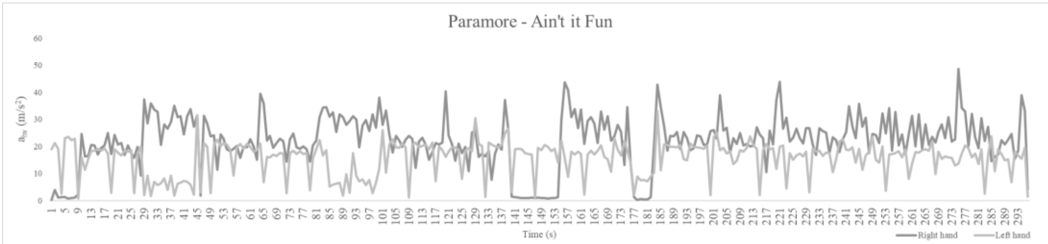

Figure F1. Drummer A – Time-history of a_{hv} for song 1 (*Paramore – Ain't it Fun*)

Figure F2. Drummer A – Time-history of a_{hv} for song 2 (*Christee Palace – Falling For You*)

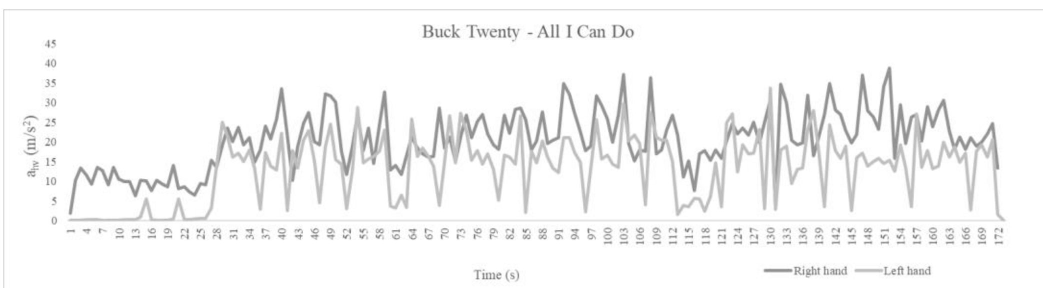

Figure F3. Drummer A – Time-history of a_{hv} for song 3 (*Buck Twenty – All I Can Do*)

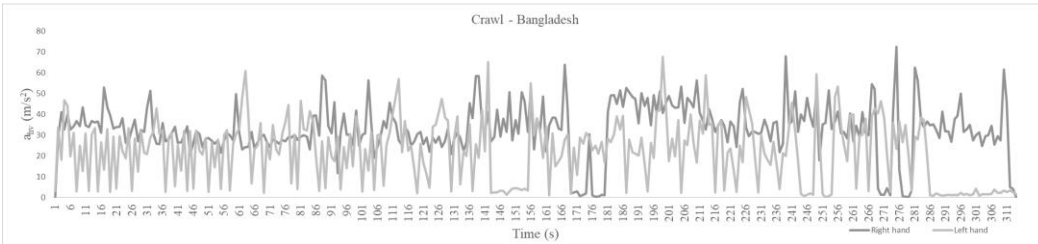

Figure F4. Drummer B – Sum of frequency-weighted RMS accelerations for song 1 (*Crawl – Bangladesh*)

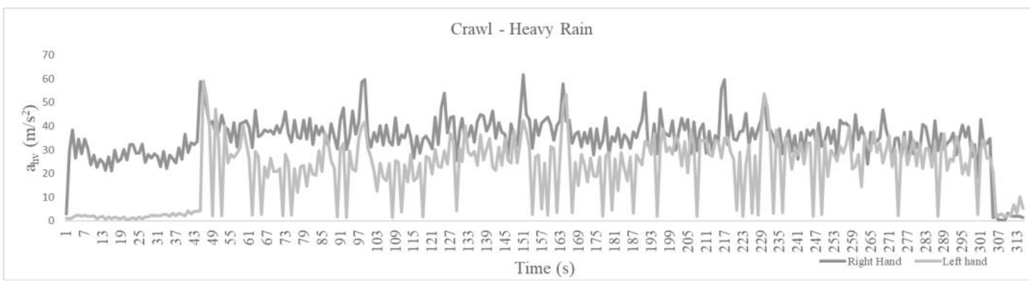

Figure F5. Drummer B – Sum of frequency-weighted RMS accelerations for song 2 (*Crawl – Heavy Rain*)

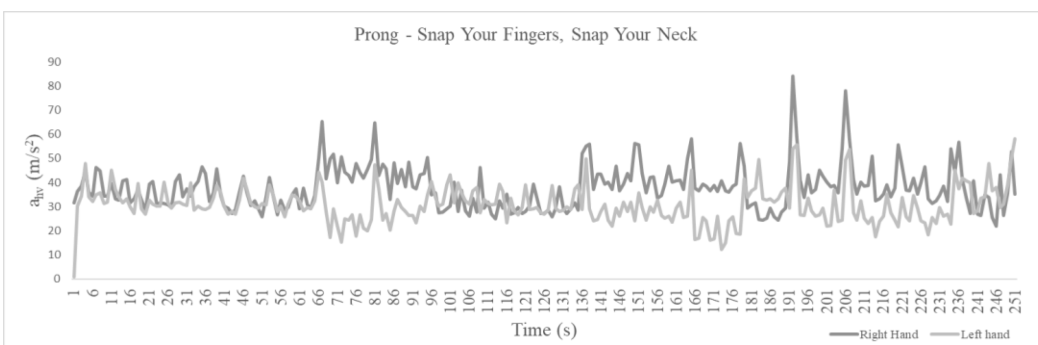

Figure F6. Drummer B – Sum of frequency-weighted RMS accelerations for song 3 (*Prong – Snap Your Fingers, Snap Your Neck*)

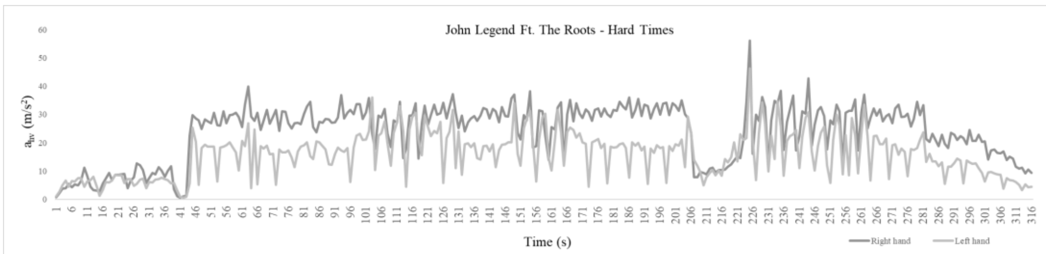

Figure F7. Drummer C – Sum of frequency-weighted RMS accelerations for song 1 (*John Legend ft. The Roots – Hard Times*)

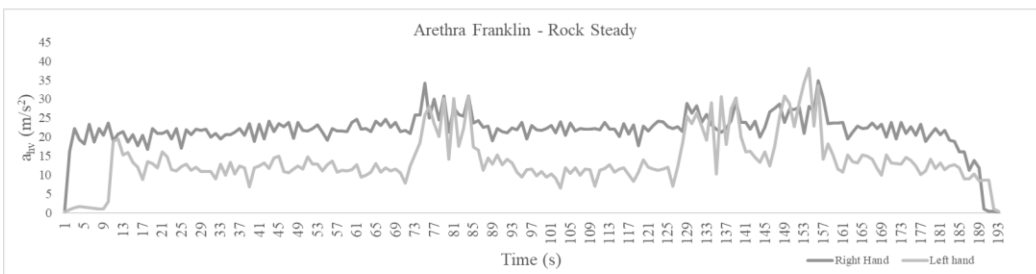

Figure F8. Drummer C – Sum of frequency-weighted RMS accelerations for song 2 (*Aretha Franklin – Rock Steady*)

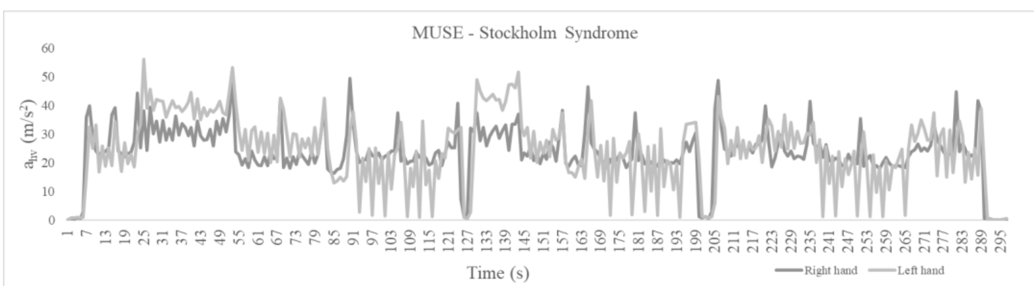

Figure F9. Drummer C – Sum of frequency-weighted RMS accelerations for song 3 (*MUSE – Stockholm Syndrome*)

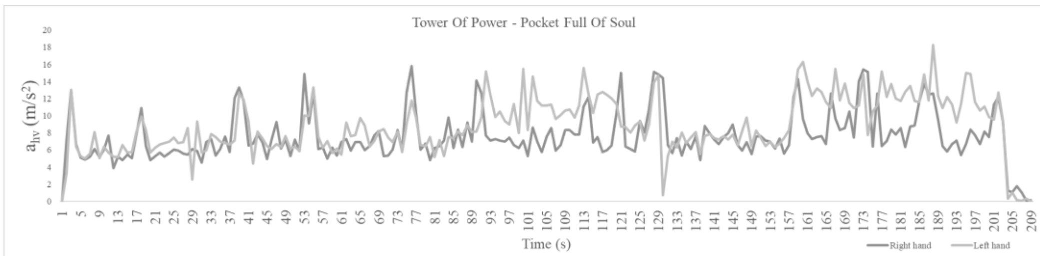

Figure F10. Drummer D – Sum of frequency-weighted RMS accelerations for song 1 in Session 1 (*Tower of Power – Pocket Full of Soul*)

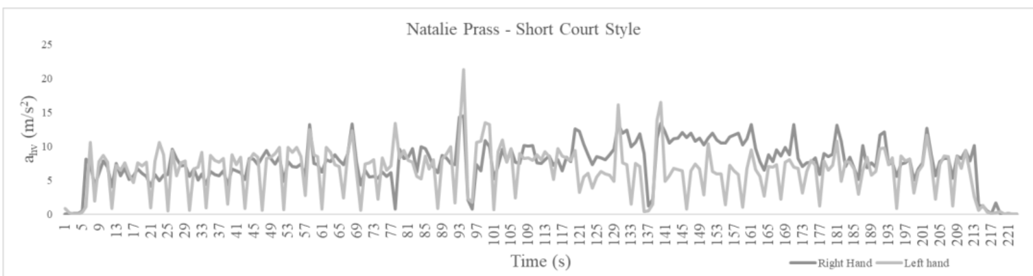

Figure F11. Drummer D – Sum of frequency-weighted RMS accelerations for song 2 in Session 1 (Natalie Prass – Short Court Style)

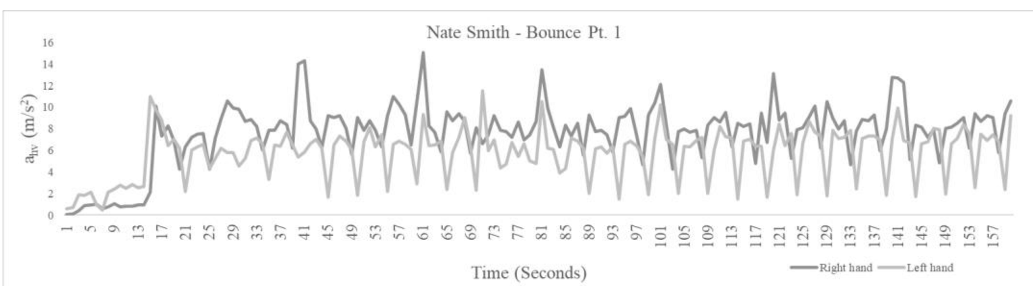

Figure F12. Drummer D – Sum of frequency-weighted RMS accelerations for song 3 in Session 1 (*Nate Smith – Bounce Pt. 1*)

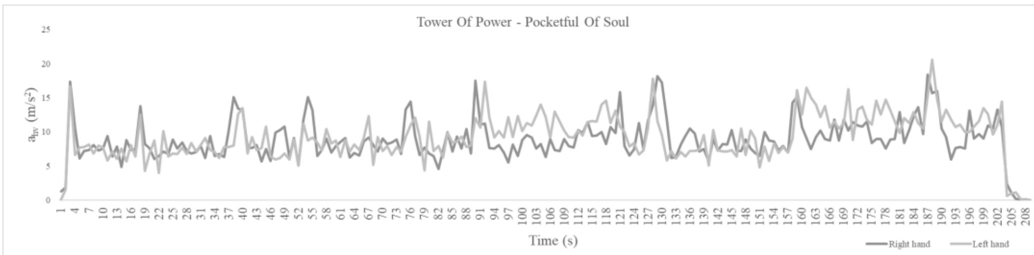

Figure F13. Drummer D – Sum of frequency-weighted RMS accelerations for song 1, session 2 (*Tower of Power – Pocket Full of Soul*)

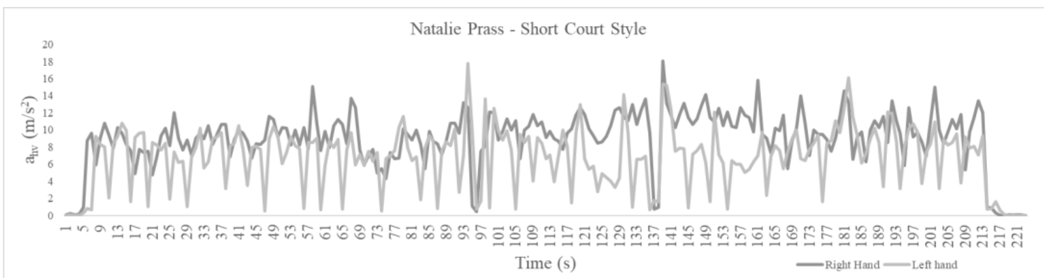

Figure F14. Drummer D – Sum of frequency-weighted RMS accelerations for song 2, session 2 (Natalie Prass – Short Court Style)

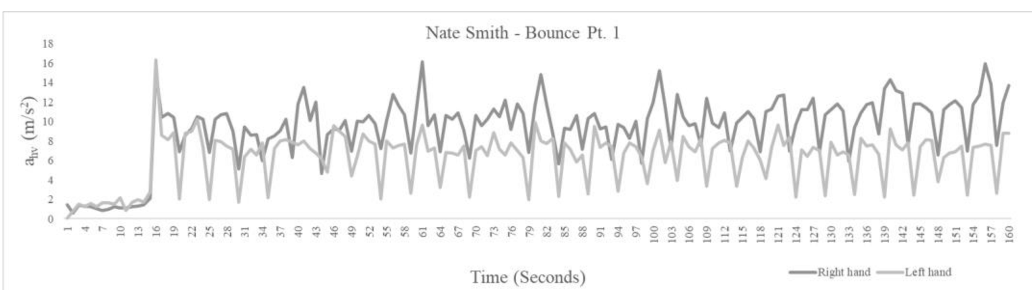

Figure F15. Drummer D – Sum of frequency-weighted RMS accelerations for song 3, session 2 (*Nate Smith – Bounce Pt. 1*)

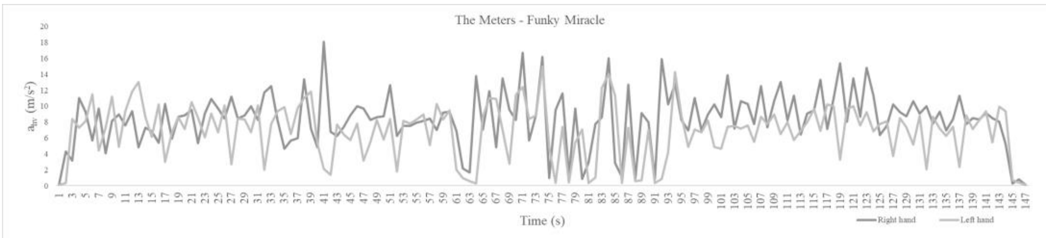

Figure F16. Drummer E – Sum of frequency-weighted RMS accelerations for song 1 (*The Meters – Funky Miracle*)

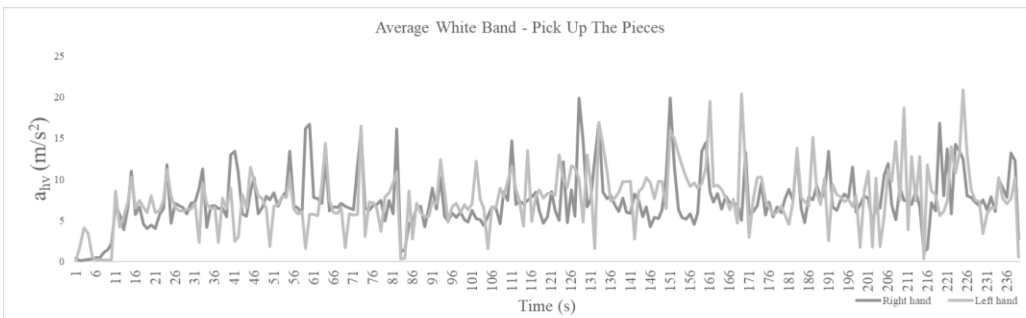

Figure F17. Drummer E – Sum of frequency-weighted RMS accelerations for song 2 (*Average White Band – Pick Up The Pieces*)

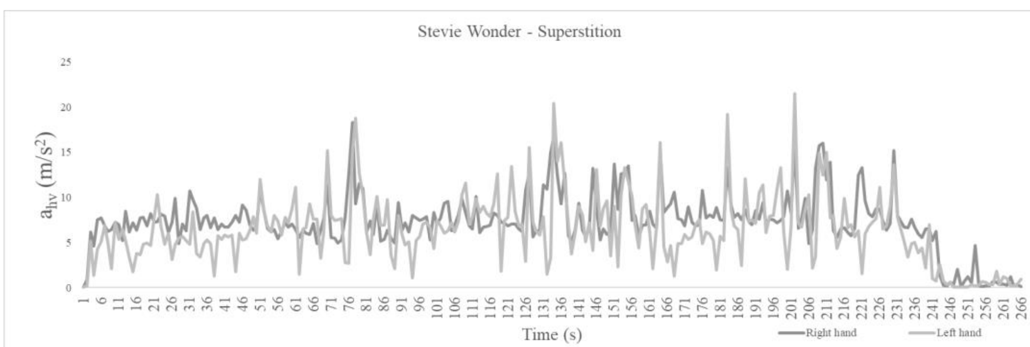

Figure F18. Drummer E – Sum of frequency-weighted RMS accelerations for song 3 (*Stevie Wonder - Superstition*)

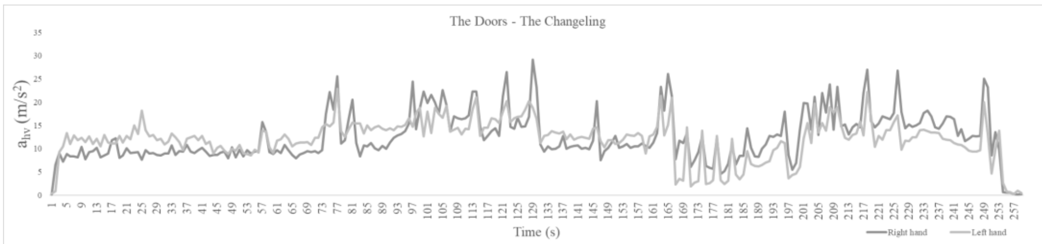

Figure F19. Drummer F – Sum of frequency-weighted RMS accelerations for song 1 (*The Doors – The Changeling*)

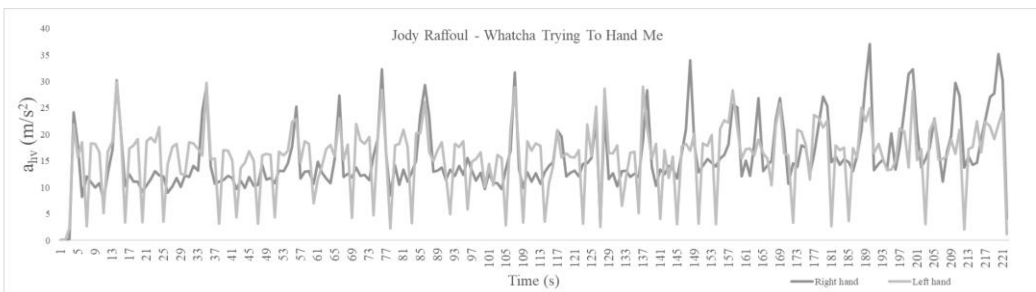

Figure F20. Drummer F – Sum of frequency-weighted RMS accelerations for song 2 (*Jody Raffoul – Whatcha Trying to Hand Me*)

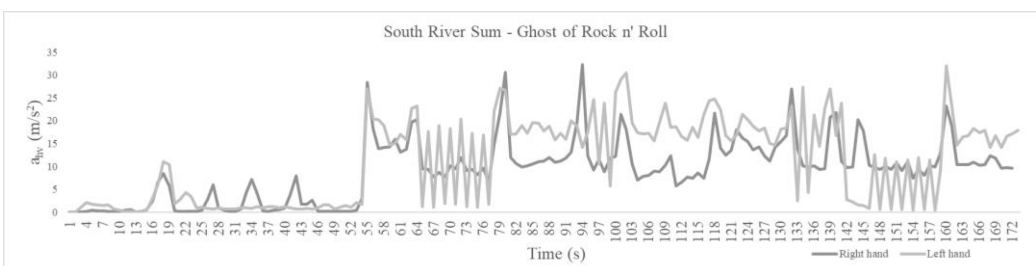

Figure F21. Drummer F – Sum of frequency-weighted RMS accelerations for song 3 (*South River Sum – Ghost of Rock n' Roll*)

VITA AUCTORIS

NAME:	Dylan Durward
PLACE OF BIRTH:	Leamington, ON
YEAR OF BIRTH:	1994
EDUCATION:	Kingsville District High School, Kingsville, ON, 2012
	Sheridan College, Hons B.A.H.Sc. (Athletic Therapy), Brampton, ON, 2017
	University of Windsor, M.H.K. (Applied Human Performance), Windsor, ON, 2022