International Journal of Kinesiology & Sports Science
ISSN: 2202-946X
www.ijkss.aiac.org.au

Evidence of a Double Pulse Muscle Activation Strategy in Drummers' Trunk and Upper Limb Muscles During High-velocity Cymbal Crashes

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ARTICLE INFO

Article history
Received: February 08, 2023
Accepted: April 20, 2023
Published: April 30, 2023
Volume: 11 Issue: 2

Conflicts of interest: None.
Funding: None

The research was funded (in part) by a Scientific Research Grant from The GRAMMY Museum®, and a University of Windsor Internal Start-up Grant. Evans Drumheads donated the drumheads used in this study.

ABSTRACT

Background: Playing the drum kit is a physically and cognitively demanding task, and skilled drummers share many such attributes with elite athletes. The 'double pulse' muscle activation (DPMA) pattern is a motor control strategy that has been observed in athletes of sports involving ballistic movements (e.g., baseball, golf, Mixed Martial Arts), and is believed to function to increase force transfer to the target. **Objective:** This study examined the muscle activation patterns of highly skilled drummers for evidence of a DPMA during high-velocity cymbal crashes. **Methods:** Five drummers were instrumented with electromyography electrodes on the right latissimus dorsi, triceps brachii, erector spinae, rectus abdominis, deltoideus posterior (DP), teres major, extensor carpi radialis, and flexor carpi ulnaris muscles. Six trials of data were collected, including a resting baseline, three maximum voluntary exertions (MVE) consisting of maximal effort cymbal crashes, a drumming pattern that included multiple crashes, and a 'free-play' trial. **Results:** The DPMA waveform was observed in all trials, but only those observed during the MVE trials were confirmed to coincide with the crashing movement via video analysis. The DP muscle – which functions to extend the shoulder joint to crash the stick on to the cymbal – exhibited confirmed DPMAs the most frequently. **Conclusion:** The extent to which drummers use the DPMA to produce high-velocity cymbal crashes within authentic playing conditions is inconclusive and needs further examination. Future study of the DPMA phenomenon in drummers would benefit from the addition of 3-dimensional motion capture to further understand the purpose of the muscle contractions of the DPMA.

Key words: Electromyography, Upper Extremity, Torso, Biomechanical Phenomena, Physical Performance, Music

INTRODUCTION

Drummers (i.e., "percussionists who play the drum kit", Azar, 2020, p. 153) must be able to coordinate their entire body in perfect harmony to create the basic rhythm and provide complex rhythmic patterns and dramatic accents within a musical piece (Reimer, 2013). Skilled performance on the drum kit requires superior coordination (Fujii & Oda, 2006; Fujii et al., 2011), error detection (Bianco et al., 2017), stamina (De La Rue et al., 2013; Dr. Nadia Azar – DRUMMER Lab, 2021), and the ability to perform complex movement patterns with apparent ease (Fujii et al., 2009a) – many attributes that are also exhibited by highly skilled athletes. Thus, playing the drum set, particularly at professional or semi-professional levels, can be considered a highly athletic endeavour.

Whether through person-to-person contact or through collisions with other objects, creating large amounts of force quickly is a crucial component of many sports, with combat sports being one of the best examples (Pinto Neto et al., 2007). Research has shown that forceful strikes can be produced by increasing the effective mass (i.e., the amount of momentum an object can transfer to another) behind the striking limb (Pinto Neto et al., 2007; Lenetsky et al., 2015). To increase the effective mass of a strike, one must increase the amount of mass behind the strike or the velocity with which the strike is delivered (Pinto Neto et al., 2007). Increasing the mass behind a strike can be accomplished by acquiring more muscle mass through workout regimens, or by increasing muscle fiber recruitment and/or using larger muscle groups while delivering a strike (Pinto Neto et al., 2007). For example, instead of relying only on the muscles of the arm, some athletes also activate their core musculature to leverage their entire body mass to deliver more powerful strikes to an opponent (e.g., McGill et al., 2010; Lenetsky et al., 2015; Lee & McGill, 2016). When it comes to increasing strike velocity, however, there is paradoxical relationship between velocity and force that athletes face when punching or kicking: when muscles contract, they

Published by Australian International Academic Centre PTY.LTD.

http://dx.doi.org/10.7575/aiac.ijkss.v.11n.2p.1

become stiff and the velocity of the movement decreases (McGill, 2011).

The double pulse muscle activation (DPMA) strategy is one mechanism by which athletes can overcome this force-velocity paradox for quick ballistic movements. The first pulse in muscle activation is associated with the initiation of limb movement, and the second pulse immediately precedes the moment of impact to support the body and transfer force onto the target (McGill et al., 2010). The period of muscle relaxation in the middle of the motion allows the limb to accelerate, increasing strike velocity and, ultimately, the effective mass of the strike (McGill et al., 2010). The DPMA has been observed in the trunk muscles of elite MMA athletes (McGill et al., 2010), and in the trunk, rotator cuff, and/or upper limb muscles when driving a golf ball (Jobe et al., 1983; McGill, 2009, Silva et al., 2013), as well as in pitching (Gowan et al., 1987) and batting a baseball (Ball et al., 2019). Thus, in sporting scenarios that require quick ballistic movements, athletes appear to use the DPMA as a motor control strategy to increase strike velocity, thereby increasing the effective mass behind the strike and the force delivered to the target.

Playing the drum kit (i.e., drumming) also requires ballistic movements to produce loud dynamics (i.e., volume), for example, during high-velocity cymbal crashes. However, research on the motor control and biomechanics of drumming is scarce. One research group used electromyography (EMG) to try to explain why drummers could achieve higher tapping frequencies during a manual tapping task than non-drummers (Fujii et al., 2009a, 2009b; Fujii & Moritani, 2012). While these studies showed that skilled drummers have more efficient muscle activation strategies, they did not examine any aspects of the mechanics of drumming beyond fast repetitive drumming, and they only examined the EMG profiles of the wrist flexor and extensor muscle groups. Another research group investigated movement patterns and timing in drumming (Dahl, 2005; Dahl et al., 2011; González-Sánchez et al., 2019). These studies indicated that highly skilled drummers were able to strike the drums with greater velocity and more force by increasing the preparatory height of a strike, but they did not use EMG to investigate the muscle activation patterns during these movements. To date, no studies have used EMG to observe muscle activation patterns during single high velocity impacts (e.g., cymbal crashes). Furthermore, no studies have monitored the activity of the proximal upper arm muscles or the torso muscles, which are most likely to be responsible for producing forceful strikes.

Given their many similarities to elite athletes, highly skilled drummers may also use the DPMA strategy to create more forceful strikes on the drums and cymbals. However, this has yet to be demonstrated in the research literature. Such information would lead to a better understanding of the biomechanics of drumming and may yield new training methods to help drummers of all skill levels produce forceful strikes more efficiently. Therefore, this study's objective was to examine the muscle activation patterns of highly skilled drummers for evidence of a DPMA during high velocity cymbal crashes.

METHODS

Participants and Study Design

This study used a multiple case study design to allow an in-depth exploration of each participant's EMG patterns. The sample size in multiple case studies is typically small (i.e., 3-4 cases) to facilitate in-depth of the investigation of the phenomenon under study (Schoch, 2020). Therefore, the investigators aimed to recruit up to five participants who met all the inclusion criteria, and none of the exclusion criteria, listed in Table 1. Rock drummers were preferred due to the physiologically demanding style of drumming (De la Rue et al., 2013; Dr. Nadia Azar – DRUMMER Lab, 2021) but drummers of all genres were eligible to participate. Potential participants were excluded from the study if they did not meet one or more of the inclusion criteria or they met one or more of the exclusion criteria.

The primary recruitment mechanisms for this study included social media and word of mouth. The host institution's Research Ethics Board reviewed and cleared all study procedures, including recruitment, and each participant granted their informed consent prior to participating in this study.

Instrumentation

EMG was used to monitor the electrical activity of the selected muscles. Self-adhesive silver/silver chloride surface electrodes were placed over the selected muscles using a bipolar configuration (Ambu Blue Sensor, N-00-S; King Medical, King City, Ontario, Canada). A reference (ground) electrode was placed over the spinous process of vertebra C7. All electrode preamplifiers were secured to the skin using medical-grade tape to prevent movement artifacts from appearing in the EMG signal (Hypafix; BSN Medical, Hamburg, Germany). The electrode leads were secured to the forearm and upper arm using self-adhesive athletic tape so they would not impede the participants' movements during the trials (BF-21-120; BQTQ, Loudi, China). The raw EMG signals were differentially amplified (alternating current amplifier, common-mode rejection ratio of 115-db at 60 Hz, gain capacity of up to 15 000: model AMT-8; Bortec Biomedical Ltd, Calgary, Alberta, Canada) and passed through an analog band-pass filter (10-1,000 Hz). The signals were then digitized through a 16-bit analog-to-digital (A-D) conversion card (NI USB-6216; National Instruments, Austin, TX) at a rate of 2,048 Hz and stored on a desktop computer.

All trials were video recorded at 30 Hz using two digital cameras to obtain a sagittal and a high-angle frontal view (Hero6; GoPro Inc., San Mateo, CA). The videos were synchronized with the EMG signals using a light that sent an electrical pulse to the EMG system when turned on and was simultaneously visible by both cameras. The EMG and light signals were acquired through the same A-D conversion card using a customized data collection program (LabView 2012, National Instruments, Austin, TX).

Drummers had to meet all the inclusion criteria, and none of the exclusion criteria, to be eligible to participate in this study.

Table 1. Study participation inclusion and exclusion criteria

Inclusion Criteria	Exclusion Criteria
Professionally established drummer (i.e., touring/recording artists, or those who regularly perform in public).	Amateur drummer or not professionally established (i.e., is not a touring/recording artist, does not regularly perform in public).
At least 18 years of age.	Less than 18 years of age.
Regularly play the drums for at least 5 hours per week (Papandreou & Vervainioti, 2010; Azar, 2020).	Does not play the drums for at least 5 hours per week on a regular basis.
Free from injuries that prevented them from playing the drums at their accustomed level of proficiency. If they had sustained such injuries within the last 12 months, they were eligible to participate if they had returned to their pre-injury drumming skill and intensity levels for at least 30 days.	Sustained an injury within the last 12 months and had not returned to their pre-injury drumming skill and intensity levels for at least 30 days.
Predominantly use a closed hi-hat/snare drumming pattern (i.e., a right-handed drummer plays the hi-hat with the right hand and the snare drum with the left hand).	Predominantly use an open hi-hat/snare drumming pattern (i.e., a right-handed drummer plays the hi-hat with the left hand and the snare drum with the right hand).
	Allergic to the ingredients in the adhesive tapes used to secure the electrodes or the electrodes themselves.
	Could not successfully perform the drum pattern described in Section 2.3 [Figure 1].

All participants played a standardized drum kit, which they were free to arrange in way that made them comfortable. The kit included a 14" snare drum, 22" bass drum, 12" and 14" rack toms, and a 16" floor tom (Pearl Drums, Decade Maple Series), each covered with Evans UV2 series drumheads. The cymbals included 14" hi-hats, 16" and 18" crashes, and a 20" ride (SABIAN XSR). The hardware included the Pearl Drums HWP-830 package with a P930/931 Longboard bass drum pedal and double-pedal conversion kit. Participants were asked to bring their own drumsticks to use during data collection.

Procedures

The study procedures were reviewed, and the participants were able to ask questions before signing the informed consent form. The participants then completed a short intake survey that included questions about participant demographics (e.g., age, preferred gender pronouns, etc.), playing history, injury history, and performance style.

The locations of EMG electrodes placement were shaved (if necessary; if the participant did not do so ahead of time as requested), cleaned with rubbing alcohol, and lightly abraded using a paper towel. EMG electrodes were placed 20 millimeters apart (Bartlett, 2007) on the selected muscles, as described in Table 2. The long head of the triceps brachii (TB) was selected for its function to extend the lower arm at the elbow, and the deltoideus posterior (DP), teres major (TM), and latissimus dorsi (LD) muscles were selected for their functions to extend the shoulder (Davis, 1959; Perotto et al., 2011), because both motions are needed during the downward crash movement. The rectus abdominis (RA) and erector spinae (ES) muscles were selected given their roles in core stabilization and their potential to demonstrate the DPMA based on previous studies (e.g., McGill et al., 2010). Finally, the flexor carpi ulnaris (FCU) and extensor carpi radialis (ECR) muscles, while not expected to display the DPMA consistently, were selected so that qualitative comparisons could be made with other studies (e.g., Fujii et al., 2009a, 2009b). Muscle activity was only recorded from the dominant side.

Table 2. Muscles of interest and EMG electrode positions

Muscle	Electrode positions
Triceps brachii, long head (TB)	Two finger widths medial and half-way down the line between the posterior crista of the acromion and the olecranon (Davis, 1959)
Deltoideus posterior (DP)	Centered in the area two finger breadths behind the angle of the acromion (Perotto et al., 2011)
Latissimus dorsi (LD)	Over the muscle belly below the inferior angle of the scapula (McGill et al., 2010)
Teres major (TM)	Along the lateral border of the scapula, three finger breadths above the inferior angle (Perotto et al., 2011)
Rectus abdominis (RA)	Two centimeters lateral to the navel (McGill et al., 2010)
Erector spinae (ES)	Approximately 5 centimeters lateral to the spinous process of T9 (McGill et al., 2010)
Flexor carpi ulnaris (FCU)	One third the distance from the medial humeral epicondyle in line with the styloid process of the radius (Davis, 1959)
Extensor carpi radialis (ECR)	One third the distance from the lateral humeral epicondyle in line with the styloid process of the radius (Davis, 1959)

A description of the guidelines followed for electrode placement over each of the target muscles.

After EMG instrumentation was complete and proper function was verified, a resting baseline trial was conducted to quantify the noise in the signals. For this trial, the participants laid supine on a massage table and were asked to relax as much as possible and lie still for two minutes. Next, the participants adjusted the drum kit to their preference and were asked to play for five minutes to warm up. Following the warmup, participants performed three maximum voluntary exertion (MVE) trials for signal normalization purposes. For these trials, the participants struck the crash cymbal on the right side of the drum kit with their right-hand drumstick as hard as they could. Then, the participants played ten repetitions of the standardized drumming pattern (Figure 1) at a tempo of 144 BPM, yielding 10 crashes per trial. This pattern was designed to mimic typical rock drumming while being simple enough for drummers to play without producing undesirable tension, but at a tempo that still required energy and stamina (N. Papador, personal communication, October 27, 2020). For all participants, the crash cymbal was positioned such that the participants were required to flex and abduct their shoulders to reach it. The last trial (i.e., ‘free-play’) consisted of the participant playing whatever they wanted (i.e., improvised patterns and fills, or part of a song) for two minutes so that muscle activation patterns could be observed in more authentic playing conditions. The video cameras recorded continuously through all trials (except baseline), but the EMG data and light on/off signal for each trial were saved as individual files.

Data Processing

The mean of each raw EMG signal was calculated and subtracted from the signal to ensure it fluctuated around a mean of zero. The “zeroed” EMG signals were high-pass filtered (cutoff frequency: 250 Hz), full-wave rectified, and then low-pass filtered (cutoff frequency: 2 Hz) using dual-pass, first-order Butterworth filters (Potvin & Brown, 2004; Staudenmann et al., 2007). The root-mean-square (RMS) amplitude of the filtered resting baseline trial (i.e., signal noise estimate) was then subtracted from every data point of the filtered MVE, pattern, and free-play trials. All trial signals (except the resting baseline) were normalized to the largest peak amplitude found among the MVE trials, pattern trials, or free-play trials. Finally, the normalized EMG signals and the light signal were downsampled to 30 Hz using a spline interpolation algorithm to match the frame rate of the video cameras. All EMG data were processed using a customized data analysis program (LabView 2021, National Instruments, Austin, TX).

To synchronize the video with the downsampled EMG signals; for each trial, the first video frame where the light was conclusively “on” was located, and the corresponding instant in the downsampled light signal was also located. The videos and the downsampled EMG signals were trimmed to include only the frames following the onset of the light signal. Thus, specific events observed in the EMG signal could be associated with specific moments in the video recordings.

Drum notation for the drum beat all participants played during ‘pattern’ trials. Image by Dr. N. Papador (October 11, 2020). Used with permission.

Data Analysis

The filtered and normalized EMG traces from each MVE, pattern, and free-play trial were examined for the presence of a DPMA, as follows: First, a visual inspection of the EMG signals at the instant of the crash was used to see if DPMAs were evident, and the presence (or absence) of a DPMA was noted for each muscle in each trial. Next, standards for the minimum absolute difference in amplitude (MAD, in units of %MVE) for the peaks and valley of the DPMA were set to examine the use of objective criteria for defining what constitutes a DPMA. When examining visual traces from previous DPMAs (McGill et al., 2010), an absolute difference in amplitude of approximately 20 %MVE between the DPMA peaks and valley appeared to be the most common MAD for traces that were deemed to contain a DPMA. MAD criteria of 10 %MVE and 5 %MVE were also selected to explore which criteria might best match the visual inspection for categorizing DPMAs. Therefore, MAD criteria of 5 %MVE, 10 %MVE, 20%MVE were examined to determine which criteria most accurately matched the visual inspections. In applying these criteria, the determination of whether a potential DPMA met each criterion was based on the absolute

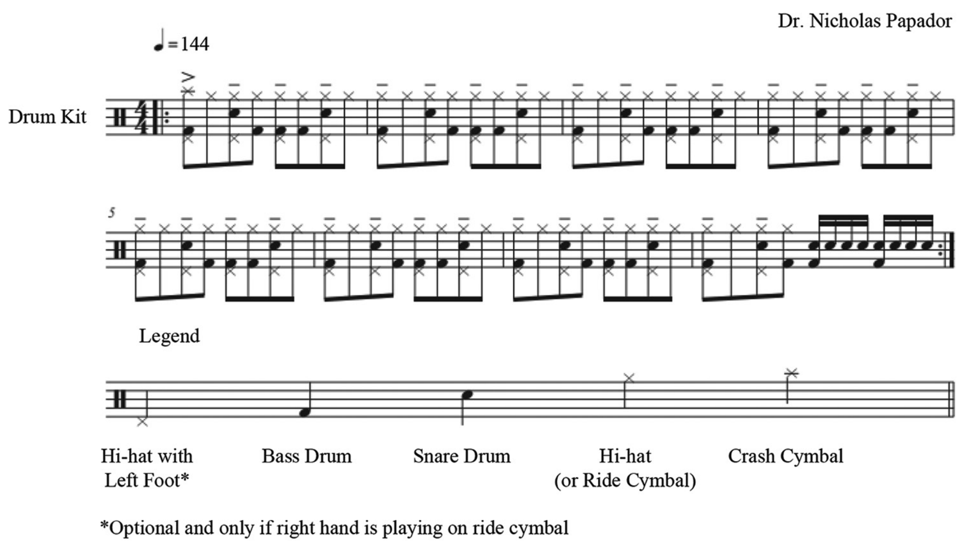

Figure 1. Standardized drumming pattern

difference in %MVE between the lower of the two peaks and the valley, to ensure both peaks met the criterion (Figure 2).

Finally, all crashes from the MVE trials that exhibited DPMAs that met the 10%MVE and/or 20%MVE criteria underwent video analysis. For the pattern and free-play trials, three crashes that met these criteria in the most muscles were selected for video analysis for each participant. These traces were examined in conjunction with the video so that observations could be made regarding the profile of the EMG signals at the instant of the high impact crash, and to confirm whether the timing of the DPMA matched the timing of the participants' crash motions. For the purposes of this study, the two pulses of the DPMA waveform must have associated with the same crashing motion to be considered a "true" DPMA.

The aim of this study was to obtain a "proof of principle" of the muscle activation patterns of drummers during high-impact crashes, and not to quantitatively compare differences between subjects. Therefore, no statistical analyses were performed on the data.

In this example, the absolute difference in amplitude (%MVE) between the lowest of the two pulses (50 %MVE) and the valley (15 %MVE) is 35 %MVE, meaning this DPMA would meet all three MAD criteria.

Inter-rater reliability analysis

An inter-rater reliability analysis was conducted to determine the degree to which visual inspection of EMG signals for DPMAs would yield similar results among different raters. Filtered EMG traces from the MVE trials from two participants were first inspected by the first author, who gave them a 'yes' (Y), 'no' (X), or 'inconclusive' (INC) rating. An 'INC' rating could have been given for many reasons, such as uncertainty regarding the magnitude of the difference in %MVE or the timing of the EMG signal with the movement. The same traces were then given to the second author, who was given no information regarding the participant to whom the EMG traces belonged, the muscles from which they were recorded, or their time course or amplitude. They were asked indicate 'Y', 'N', or 'INC' to the presence of a DPMA solely based on the shape of the waveform. A percentage agreement (P_a) was determined by calculating the quotient of matching responses (M_r) and the number of waveforms inspected (W), using the following equation:

$$P_a = \frac{M_r}{W} \times 100 \qquad \text{Eq. (1)}$$

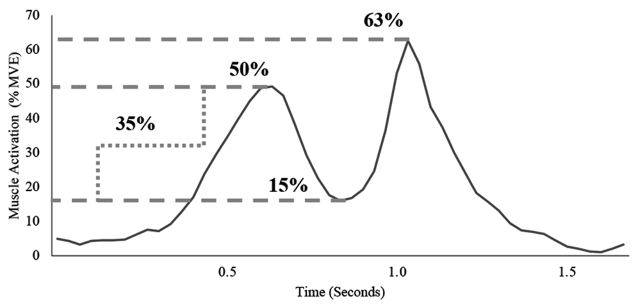

Figure 2. Example of MAD in %MVE criterion calculation

RESULTS

Participants

Five adult drummers (ages: 24 to 45 years), all of whom self-identified as men, participated in this study. A summary of the intake survey data (i.e., age, start age of playing drums, weekly playing hours, and average paying session duration) across the five participants are presented in Table 3. The participants' data have been de-identified and therefore, participants will be referred to as Drummer A-E, and he/him pronouns will be used. All the participants were right hand dominant, used a closed hi-hat/snare pattern, and used matched grip style. All participants were able to play to the intensity and skill level they are accustomed to for at least 30 days prior to data collection. One participant (Drummer D) requested to use his own kick pedal. Given that the focus of this study was on the upper limbs, this request was granted.

Group means (standard deviations in brackets) of responses to demographic questions from the intake survey.

Inter-rater Reliability Analysis

Twenty-four waveforms from three randomly chosen MVE trials from Drummers A and B were examined. Both raters agreed on the presence/absence of a DPMA in 20 waveforms (P_a = 83.3 %: Table 4). The four waveforms where the raters did not agree occurred in the TB, ES, TM, and ECR, respectively. In those disagreements, one rater chose an 'INC' rating whereas the other rater gave a rating of 'Y'. A percentage agreement above 75 % is considered acceptable in most fields (Goodier, 2011).

Agreement on the presence/absence of a DPMA upon visual inspection was achieved in 20 out of 24 EMG traces (83.3%). 'Y': DPMA present, 'X': DPMA not present, 'INC': inconclusive.

DPMA Analysis

Table 5 presents the frequencies with which each muscle displayed a DPMA (in any trial) that met at least the 10 % MVE criterion. In total, 77 crashes were examined across all five participants. The 10 %MVE criterion was chosen as it seemed to coincide most consistently with a positive visual inspection. There were many instances where a DPMA with an inconclusive visual inspection met the 5 % criterion only, or none at all. The DP and TB exhibited DPMAs the most frequently, followed by the TM and LD. The ES, RA, FCU, and ECR muscles very rarely displayed a DPMA, and in the cases of the FCU and ECR, there was frequently too much muscle activity to make detection of a DPMA possible (Figure 3).

Table 3. Participant demographic information

Current age (years)	Average age of playing onset (years)	Average weekly playing time (hours)	Average duration of playing session (hours)
34.6 (7.6)	10.4 (4.9)	7.8 (2.2)	1.4 (0.5)

Table 4. Results of the inter-rater reliability analysis

Trial	Rater	Muscle							
		LD	TB	ES	RA	DP	TM	FCU	ECR
Drummer A, MVE 3	1	X	INC	X	X	Y	INC	X	X
	2	X	Y	X	X	Y	Y	X	X
Drummer B, MVE 2	1	X	X	INC	X	Y	X	Y	X
	2	X	X	Y	X	Y	X	Y	X
Drummer A, MVE 1	1	X	Y	X	X	Y	Y	X	Y
	2	X	Y	X	X	Y	Y	X	INC

Table 5. Frequencies of DPMAs observed across all participants (77 crashes examined)

Trial	Decision Criterion	Muscle							
		LD	TB	ES	RA	DP	TM	FCU	ECR
MVE	10%	1	2	1	0	8	2	1	4
	20%	1	0	0	0	4	2	2	0
Pattern	10%	14	17	0	3	30	17	0	0
	20%	0	7	0	3	6	0	0	0
Free-play	10%	4	3	0	0	3	2	0	0
	20%	4	5	0	0	6	5	0	0
Overall Frequency Count (% of total, n=77)		24 (31.2)	34 (44.2)	1 (1.3)	6 (7.8)	57 (74.0)	28 (36.4)	3 (3.9)	4 (5.2)

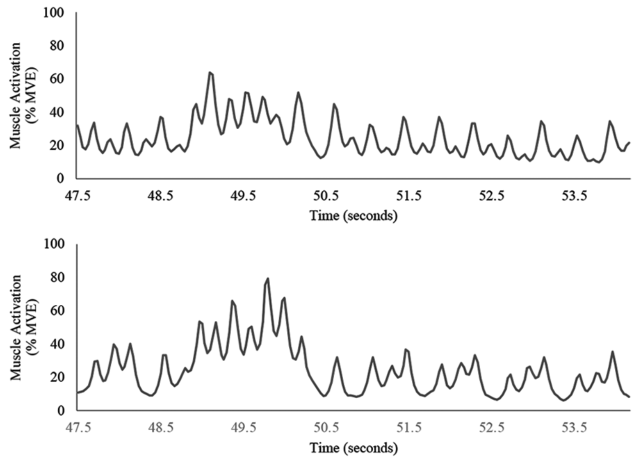

Figure 3. Sample FCU (top) and ECR (bottom) traces during a crash within the pattern trial for Drummer A

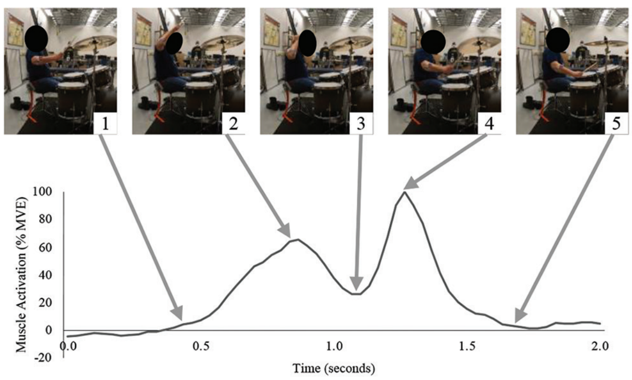

Figure 4. Video frames associated with key moments of the DP muscle DPMA of Drummer A during a MVE trial

DPMAs occurred most frequently in the DP, TM, and LD (shoulder extension) and the TB (elbow extension). Each DPMA was counted once based on the highest criterion met.

These muscles were too active to observe DPMAs during the crashes.

In total, videos from 41 crashes were examined along with the EMG traces. When reviewing the videos and EMG traces from the MVE trials, similar patterns were seen across all participants. During the MVE trials, the first pulse would occur between the middle and the peak of the upper limb raise before lowering and extending the arm and forearm to crash on the cymbal, where the second pulse would occur (Figure 4). For the pattern trial, the first pulse was frequently associated with the snare drum roll preceding the cymbal crash, where the second pulse would emerge. The DPMAs observed in the free-play trials appeared to be related to separate consecutive crashes on the cymbals and drums. In both the pattern and free-play trials, the two pulses of the DPMA waveforms were associated with different movements, and thus could not be considered "true" DPMAs. Table 6 presents the total number of "true" DPMAs, all of which were observed in MVE trials.

DISCUSSION

This study offers preliminary evidence of the presence of the DPMA strategy in some upper limb muscles of highly skilled drummers while performing high velocity cymbal crashes. The percent agreement between the two analysts performing visual inspection of a subset of potential DPMAs (83 %) was well above the threshold for acceptable inter-rater agreement (i.e., 75 %: Goodier, 2011). The criterion of a MAD of at least 10 %MVE most consistently coincided with a positive identification of a DPMA through visual inspection and was

Table 6. Frequencies of "true" DPMAs observed across all participants (41 crashes examined)

Decision Criterion	**Muscle**							
	LD	**TB**	**ES**	**RA**	**DP**	**TM**	**FCU**	**ECR**
10%	1	1	0	0	8	2	1	2
20%	0	0	0	0	4	3	2	0
Overall Frequency Count (% of total, n=41)	1 (2.4)	1 (2.4)	0 (0.0)	0 (0.0)	12 (29.3)	5 (12.5)	3 (7.3)	2 (4.9)

therefore selected as the objective criterion for identifying potential DPMAs for this study. Across all trials, DPMAs that met or exceeded the 10 %MVE criterion were exhibited most frequently by the DP and TB muscles, followed by the LD and TM. However, when the EMG traces were reviewed in conjunction with the video trials, the DPMAs identified within the MVE trials were the only ones whose timing coincided with the upper limb movement during the crash movement. Thus, only the DPMAs observed during the MVE trials could be considered "true" DPMAs. The DP muscle exhibited "true" DPMAs the most frequently, and the most consistently across the five participants.

Elite athletes in the sports of MMA, golf, and baseball have all exhibited DPMAs, which are believed to be a strategy to increase the velocity and force of striking movements (McGill et al., 2010; Silva et al., 2013; Ball et al., 2019). In many ways, skilled drummers have been shown to be physically and cognitively similar to elite athletes, and they have quicker muscle activation and relaxation rates than non-drummers (e.g., Fujii et al., 2009b; Bianco et al., 2017; Dr. Nadia Azar – DRUMMER Lab, 2021). In this study, "true" DPMAs were observed in the DP muscle in five highly skilled drummers. One drummer also exhibited "true" DPMAs in the TM, LD, and TB muscles. The main actions of these muscles include extension at the shoulder joint (LD, DP, TM) and at the elbow joint (TB) (Tortora & Derrickson, 2018) – both of which are necessary for the crashing motion. When delivering crashes, drummers must first flex the shoulder to raise the upper limb above their heads, then extend the shoulder and elbow joints to lower the upper limb down upon the drums and cymbals. The faster and harder they extend the shoulder and elbow joints; the more force will be transferred to the drums and cymbals to create louder volume levels. The DP, TB, LD, and TM muscles will all assist in the crashing action of the upper limb and, in theory, the DPMA would help them to produce more velocity and force.

The first pulse occurred near the time of peak shoulder flexion (Frame 2) and the second occurred near the time of impact with the crash cymbal (Frame 4).

The DP muscle exhibited "true" DPMAs most frequently. Each DPMA was counted once based on the highest criterion met. "True" DPMAs were only observed in the MVE trials.

The core muscles (RA and ES) did not exhibit many DPMAs that met the 10 %MVE criterion, nor did the forearm muscles (FCU and ECR). None of the DPMAs from the RA and ES were "true" DPMAs; one participant exhibited "true" DPMAs in the FCU, and another participant exhibited "true" DPMAs in the ECR. The forearm muscles were not expected to display the DPMA to the same extent as the others, because their actions were not consistent with the motion needed to perform a cymbal crash. However, based on previous studies (McGill et al., 2010; Silva et al., 2013; Ball et al., 2019), the core muscles were expected to display the DPMA more frequently and were considered main muscles of interest for this study. The RA and ES muscles function to flex the torso and extend the spine (respectively) while also bracing the core to stabilize the body (Tortora & Derrickson, 2018). The muscle activation patterns of the trunk muscles observed in this study suggested that these muscles were not as important as the upper limb and back muscles when creating cymbal crashes, particularly under more authentic drumming conditions (e.g., pattern and free-play trials). In these situations, quick movements from the shoulder and elbow joint may be more important to deliver crashes. Furthermore, the drummer sits on a throne (i.e., a stool without a back) when playing, restricting the amount of movement that is possible at the trunk and reducing the need to activate their core muscles as much to initiate movements and brace for impact when delivering strikes with the right arm. Rather, the core muscles' function may be to stabilize the body to help the drummer stay in position on the throne. This study's findings suggest that this was the case: the core muscles were primarily used to stabilize the body with tonic activation, rather than for power with phasic activation as seen with other sports.

To compare this study's participants to the athletes in previous studies, the double pulses must have represented the same specific instances of movement (i.e., initiation of movement toward target and impact with target, respectively). Previous studies indicated that the first pulse of the DPMA represented the muscle activation that initiated movement towards the target. By contrast, in all participants the first pulse observed in the MVE trials did not quite coincide with the initiation of the downward arm movements; instead, the EMG appeared to capture both eccentric contractions to slow the upper limbs' flexion trajectories and concentric contractions to accelerate in the opposite direction (i.e., extension). The second pulse occurred at or slightly before contact between drumstick and cymbal, which suggests that the drummers were preparing for impact by stiffening the arm to transfer force. The relaxation in muscle activity between the two pulses was used to accelerate the limb to increase impact velocity. Given that the MVE crash movement was one quick fluid movement, and the EMG traces had to be downsampled to match the much lower sample rate of the cameras (i.e., from 2048 Hz to 30 Hz), it was not possible to conclusively separate the concentric and eccentric phases of the muscle contraction without a more detailed kinematic analysis. Further studies using three-dimensional motion capture to gather quantitative data such as segment accelerations, joint kinematics, and body orientation would be beneficial for a better understanding of the timing of muscle activation patterns during arm flexion and extension.

The video analysis of the pattern and free-play trials indicated that the DPMAs observed in the EMG traces were not related to one singular cymbal crash, and therefore, could not be considered "true" DPMAs. In the pattern trial, the DP, LD, TB, and TM muscles would activate first to bring the arm to the snare drum for the snare roll and then the second pulse would extend the arm crashing down on the cymbal. This observation may be explained by a key difference between the present study and previous work: all previous studies of the DPMA only included singular, MVE-type movements. For example, DPMAs were observed when the MMA fighter delivered one single kick or punch (McGill et al., 2010), and when the golfer and baseball player would hit the ball in one movement (Silva et al., 2013; Ball et al., 2019). These movements are similar to the MVE trial in this study, where the participants crashed on one cymbal with one motion. In baseball and golf, there is only ever one movement to contact the ball. However, MMA, like drumming, is a highly dynamic activity where the body is in constant motion and the athlete must adapt to changing situations. McGill et al. (2010) did not include any trials that simulated fight conditions, where the athlete would be in a constantly evolving situation. In the current study, "true" DPMAs were observed in drummers during the MVE trials, but not in the pattern and free-play trials. It is possible that in real fighting situations, the MMA athletes also would not have enough time to produce a DPMA when striking, similar to what was observed in the drummers in this study during the pattern and free-play trials.

After examining all apparent DPMAs, the 10 %MVE criterion was deemed the most appropriate for identifying DPMAs. There was too much inconsistency between the visual inspection for DPMAs and the 5 %MVE criterion, and therefore this criterion was determined to be inappropriate for the context of this study. This incongruence did not occur as often using the 10 %MVE criterion. The 20 %MVE criterion was determined to be too large because there were many obvious DPMAs that did not meet the 20 %MVE criterion but did meet the 10 %MVE criterion. Therefore, the 10 %MVE criterion was selected as the minimum absolute difference in normalized amplitude between the lowest peak and the valley of the DPMA waveforms that could be considered a potential DPMA. This study has attempted to set an objective numerical criterion to define a DPMA, as previous studies did not use any objective criteria for identifying a muscle activation pattern as a DPMA (McGill et al., 2010; Silva et al., 2013; Ball et al., 2019). Future studies can utilize this criterion as a starting point to objectively identify DPMAs beyond visual inspection of EMG traces.

Limitations

The safety regulations imposed by the SARS-CoV-2 pandemic created many obstacles in the completion of this study. Participant recruitment became limited to the point where the sample size was adjusted to include five drummers in a multiple case study design. Thus, the goal of the study became to obtain a proof of principle that a DPMA would emerge in the EMG profiles of a limited number of highly skilled drummers. Also, maximal voluntary contraction (MVC) trials were not collected, to limit the number and duration of breaches of physical distancing requirements during data collection. MVEs were considered a reasonable substitute because the motion for an MVE is more realistic to true drumming performance than a static contraction against resistance. In many cases, peak muscle activation levels will occur during the task under investigation rather than the MVC trials (Halaki & Ginn, 2012). However, MVC trials can be collected in future studies to obtain the maximal amount of force production and activation for each muscle.

The MVE trials in this study did not provide ideal conditions to enable the interpretation and display of a DPMA. The participants performed the MVE starting from the resting position as one fluid motion, as that is what is generally used in performance. It would have been more beneficial to have the participant raise their arm, then pause for a moment before crashing down upon the cymbal. That way, it would be very clear what the purpose of the individual pulses in the MVE trial were. By restricting the crash to a singular motion, and with the inclusion of 3-dimensional motion capture, muscle activation associated with the initiation of the downward movement would have more distinguishable from the muscle activation associated with the upward arm motion. Finally, during the pattern and free-play trials, the participants appeared to use arm abduction and adduction (i.e., a "reach and push" motion) to move from the drums to the cymbal, rather than extension. The muscles involved in these motions may have exhibited the DPMA, but they were not monitored with EMG so this could not be captured. Future studies could build on the results of this work by monitoring more of the shoulder abductor (i.e., middle deltoid and supraspinatus) and adductor muscles (i.e., anterior deltoid, pectoralis major).

Strengths and Practical Implications

Despite the limitations, this study has contributed to the limited literature on the biomechanics and motor control of drumming. The multiple case study approach allowed an in-depth qualitative analysis of the participants' EMG traces, which would not have been feasible to the same extent with a larger sample size. Likewise, the smaller sample size enabled the inclusion of multiple playing conditions in which to potentially observe DPMAs (e.g., single motion, prescribed pattern with crash, and free-play). The objective criteria to identify potential DPMAs can be used in future research to help standardize and simplify the identification of DPMAs, rather than relying solely on visual inspection, in drummers and non-drummers alike.

Although only one muscle in this study exhibited "true" DPMAs consistently (i.e., the DP), its appearance opens the possibility of more research in this field. Future studies that address the limitations described above may yield more frequent/consistent observations of the DPMA, and/or in more muscles. Such information would provide drummers of all skill levels with a visualization of how louder and more forceful cymbal crashes are created, allowing skilled drummers to refine their skills, and giving amateur drummers a specific goal to achieve through their training.

CONCLUSION

This study has demonstrated that the DPMA does occur within the EMG profiles of drummers during singular, high velocity cymbal crashes. The DP, TM, LD, TB, FCU, and ECR muscles exhibited apparent DPMAs during the MVE trials, with the DP muscle doing so the most consistently (particularly with "true" DPMAs). The first pulse appeared to capture both the eccentric contraction to stop shoulder flexion and concentric contraction to initiate shoulder extension. The second pulse frequently coincided with preparation for contact with the cymbal to transfer force. The relaxation in between the two pulses allowed the limb to accelerate to increase striking velocity and effective mass. To our knowledge, this is the first time the DPMA pattern has been observed in drummers, but the extent to which drummers use the DPMA is inconclusive and needs further examination. Suggestions for future studies include 1) adding motion capture to enable quantitative analysis of 3-dimensional joint kinematics, 2) modifying procedures for MVE trials and including MVC trials, and 3) changing which muscles are monitored by removing the wrist muscles and adding shoulder abductors. All of these will enable a better understanding of the use of the DPMA by drummers and, along with the current study, will add to the literature on the biomechanics and motor control of drummers and increase knowledge of the athletic qualities exhibited by highly skilled drummers.

ACKNOWLEDGMENTS

This study was funded (in part) by a Scientific Research Grant from The GRAMMY Museum®, and a University of Windsor Internal Start-up Grant. Evans Drumheads donated the drumheads used in this study. The authors gratefully acknowledge the support and contributions of the following individuals and organizations: Dr. Nicolas Papador, Chad Sutherland, and Denis Beaulieu (University of Windsor); Aaron Vishria (Evans Drumheads); Chris Stankee (SABIAN Cymbals); John Farquharson (Pearl Drums); Chad Brandolini (Vater Percussion); Peter Marunzak (Erikson Music); Casey Grillo (Drumstatic); the study participants; and the sources of funding/support listed above.

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