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Striking dynamics and kinetic properties of boxing and MMA gloves

Benjamin LEE & Stuart MCGILL*

Spine Biomechanics Laboratory, University of Waterloo (Canada)

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ORIGINAL PAPER

Abstract

With the growing popularity of Mixed Martial Arts (MMA) as a competitive sport, questions regarding the dynamic response and properties of MMA gloves arise. High-energy impacts from punches are very similar to boxing yet MMA competition requires the use of 4 oz fingerless glove, compared to the larger full enclosure boxing glove. This work assessed the kinetic properties and strike dynamics of MMA gloves and compared findings with traditional boxing gloves. Gloves mounted on a molded fist were impacted repetitively on an instrumental anvil designed for impact, over a 5 hour period resulting in 10,000 continuous and consistent strikes. Kinetic data from impacts were sampled at the beginning of the data collection and subsequently every 30 minutes (every 1,000 strikes). MMA gloves produced 4-5 times greater peak force and 5 times faster load rate compared to the boxing glove. However, MMA gloves also showed signs of material fatigue, with peak force increasing by 35% and rate of loading increasing by 60% over the duration of the test. Boxing glove characteristics did deteriorate but to a lesser extent. In summary, the kinetic properties of MMA glove differed substantially from the boxing glove resulting in impacts characterized by higher peak forces and more rapid development of force. Material properties including stiffness and thickness play a role in the kinetic characteristics upon impact, and can be inferred to alter injury mechanisms of blunt force trauma.

Keywords: Strike; glove; MMA; safety; boxing; force; combat sports; martial arts.

Dinámica de golpeo y propiedades cinéticas de guantes de boxeo y de MMA

Resumen

La creciente popularidad de las Artes Marciales Mixtas (MMA) como deporte competitivo ha suscitado preguntas sobre la respuesta dinámica y propiedades de los guantes de MMA. Los impactos de alta potencia de los puñetazos en MMA son muy similares a los del boxeo, pero en la competición de MMA se utilizan guantes de 4 onzas sin dedos, en contraste con los guantes de boxeo que son totalmente cerrados. Este estudio evaluó las propiedades cinéticas y la dinámica de golpeo del guante de MMA y comparó los resultados con los del guante de boxeo tradicional. Los guantes, montados en un puño moldeado, fueron golpeados repetidamente sobre un yunque instrumentado diseñado para los impactos durante un periodo de 5 horas en el que se realizaron 10.000 golpes continuos y consistentes. Los datos cinéticos de los impactos se muestrearon al principio de la toma de datos y seguidamente cada 30 minutos (cada 1.000 golpes). El guante de MMA produjo un pico de fuerza 4-5 veces mayor, y un índice de carga 5 veces más rápido que los guantes de boxeo. También, el guante de MMA mostró síntomas de fatiga del material, con incrementos de la fuerza pico del 35% y del índice de carga del 60% a lo largo del test. Las características del guante de boxeo

Dinâmica dos golpes e propriedades cinéticas das luvas de boxe e de MMA

Resumo

A crescente popularidade das Artes Marciais Mistas (MMA), como desporto competitivo, tem suscitado questões sobre a dinâmica e as propriedades das luvas de MMA. Os impactos de alta potência dos socos em MMA são muito similares aos do boxe, mas na competição de MMA utilizam-se luvas de 4 onças sem dedos, em contraste com as luvas do boxe que são totalmente fechadas. Este estudo analisou as propriedades cinéticas e a dinâmica dos socos das luvas de MMA e comparou os resultados com as luvas de boxe tradicional. As luvas, calçadas num punho moldado, foram golpeadas repetidamente sobre um aparelho instrumentalizado, desenhado para os impactos dos socos durante o período de 5 horas, em que se realizaram 10.000 socos contínuos e consistentes. Os dados cinéticos dos impactos foram recolhidos no início e seguidamente em cada 30 minutos (cada 1.000 golpes). As luvas de MMA produziram um pico de força 4-5 vezes maior e um índice de carga 5 vezes mais rápido do que as luvas de boxe. As luvas de MMA mostraram também alguma fatiga do material, com incremento da força pico de 35% e no índice de carga de 60% no decurso do teste. As características das luvas de boxe também se deterioraram, mas em menor medida.

* *Email :* mcgill@uwaterloo.ca. *Address:* Spine Biomechanics Laboratories, Faculty of Applied Health Sciences, Department of Kinesiology. University of Waterloo, Waterloo, Ontario, Canada, N2L 3G1.

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también se deterioraron pero en menor medida. En resumen, las propiedades cinéticas del guante de MMA se diferenciaron sustancialmente de las del guante de boxeo, resultando en impactos caracterizados por fuerzas pico más altas y un desarrollo de fuerza más rápido. Las propiedades del material, incluyendo la rigidez y el grosor, juegan un papel en las características cinéticas del impacto, y se puede deducir que alterarán los mecanismos de lesión producidos por traumatismos contundentes.

Palabras clave: Golpeo; guante; MMA; seguridad; boxeo; fuerza; deportes de combate; artes marciales.

Em resumo, as propriedades cinéticas das luvas de boxe de MMA diferenciaram-se substancialmente das luvas de boxe, resultando impactos caracterizados por forças pico mais altas e o desenvolvimento de força mais rápida. As propriedades do material, incluindo a rigidez e a espessura, têm um papel fundamental nas características cinéticas do impacto. Pode-se, assim, deduzir que se alteram os mecanismos de lesão produzidos pelos traumatismos contundentes.

Palavras-chave: Golpes; luvas; MMA; segurança; boxe; força; desportos de combate; artes marciais.

1. Introduction

Striking based combative sports such as boxing uses padded gloves intended to reduce injury. Mixed martial arts (MMA), which involves similar striking patterns, has experienced a rise in popularity. However, the rules of the sports differ in the size and design of gloves. Professional boxing regulations state the use of eight and ten-ounce closed fisted boxing gloves for competition purposes (World Boxing Council, 2011), while larger fourteen and sixteen-ounce gloves are often used in training. In contrast, MMA rules require the use of a much lighter four-ounce fingerless MMA gloves (New Jersey State Athletic Control Board, 2002). While strike dynamics of boxing gloves have been examined (Smith & Hamill, 1985; Smith, 1987) the characteristics of MMA gloves have remained untested, motivating the work performed in this experiment.

Understanding the impact properties of equipment used in combat sports would serve several purposes. For example, testing of the equipment itself would provide manufacturers with data for research and development leading to design specifications. Those interested in injury would also profit from understanding the differences in impact attenuation properties and how they may change over repeated impact. Finally, those interested in the long term consequences of combat sport participation would be assisted with comparative equipment data.

The rational for using padded gloves is two fold: to protect the carpals and wrists of the striker, and to absorb the impact of blows received by the opponent. Numerous safety concerns have arisen for both rationales in which investigation of hand and wrist injuries (Noble, 1987; Dincer, 2007) as well as head injuries (British Medical Association, 1993; Jordan, 2000; Rabadi & Jordan, 2001; Bledsoe, Li, & Levy, 2005; McKee, et. al., 2009) have been performed. Such concern for safety reinforces the high risk nature of the sport of boxing. MMA, a much younger sport, has not had such a longstanding investigation into its safety (Bledsoe, Li, & Levy, 2005; Ngai, Levy, & Hsu, 2008). Currently, in terms of hand striking, differences in the impact characteristics and potential injury to the striker and opponent are unknown between the two types of gloves.

Smith and Hamill (1985) and Smith (1987) performed many analyses of the impact characteristics of boxing gloves using a gravity driven drop tower to collect kinetic and time varying data. While this drop tower provides a suitable means of collecting single consistent strikes, collecting data over an extended period of time with thousands of strikes would prove challenging given the manual reset. Furthermore, it should be noted Smith's experiments occurred over 20 years ago; materials used in the manufacturing of boxing gloves has changed substantially over this period from "a layer of hair sandwiched between two layers of open cell foam covered with a leather sheat" (Smith & Hamill, 1985, p. 124) to various composite core materials such as those used in this study. Thus, raw values of force, impulse and rate of force from Smith's seminal work may have changed with the evolution of glove materials.

Given the dearth of data describing the properties of MMA gloves, this study compared MMA and boxing gloves. It was hypothesized that MMA gloves would result in a greater peak force and faster time to peak value than the boxing glove. Furthermore, given the thinner core construction profile of the MMA glove, retention of impact characteristics with repeated strikes would be compromised as material fatigue would occur, resulting in greater increases in peak force.

2. Methods

2.1. Research design

The kinetic impact properties of MMA gloves were compared with boxing gloves using a custom fabricated repetitive pendulum based impact tester (Fig. 1) designed to create repetitive but controlled impacts. Repeated impacts were made and recorded to simulate continuous wear on the gloves. Prior to glove testing raw core materials used in glove construction were also tested for better understanding of the effect of the strikes and foam density. Testing occurred at room temperature (approximately 23°C). Four-ounce MMA gloves (approximately 1 cm padding thickness) and sixteen-ounce boxing gloves (approximately 2 cm padding thickness) (Hayabusa Fightwear, Kingston, Canada) (Fig. 2) were mounted to a biofidelic fist model to simulate stress concentrations associated with a human fist. Materials used in the construction of MMA and boxing gloves consisted of premium cowhide leather (65%), nylon/polyurethane foam complex (18%) and a patent pending polyethylene/latex rubber foam composite (17%).

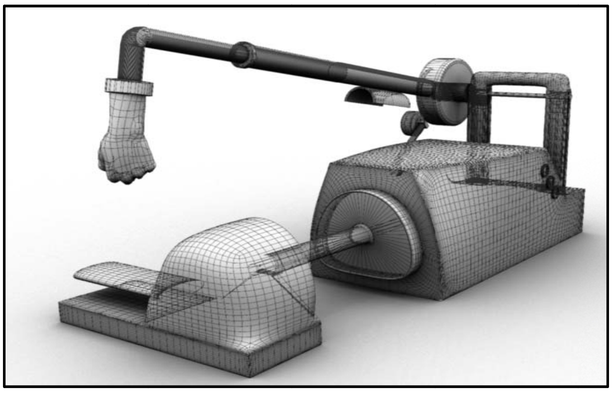

Figure 1. Schematic diagram of pendulum based impact tester used in experiment.

Figure 2. 16 oz boxing gloves (left) and 4 oz MMA gloves (right) used in impact tests. Gloves were mounted to the impact tester (Fig. 1) and impact characteristics collected over 5 hours/10,000 strikes.

Each glove was attached to the fist model and taped at the wrist to simulate the taping of a glove closure during competition. Data was collected over a five hour period, sampling force-time characteristics over 20 strikes every 30 minutes and ensemble averaging the response during this period; impacts occurred once every 1.8 seconds resulting in 10,000 strikes over the collection period. Impacts were made to a portable 'pancake' force transducer designed for impact use (AMTI, Massachusetts, USA). Impact data was sampled at 2160 Hz and filtered with a 2^{nd} order dual pass Butterworth filter with cutoff frequency of 100 Hz. Cutoff frequency was determined using a fast fourier transformation; filtering, processing and analysis was performed via MATLAB software (Version r2012a; The MathWorks Inc., Natick, Massachusetts, USA).

2.2. Statistical Analysis

Multiple statistical analysis tools were used given the variety of data and hypotheses to be examined. All statistical analysis was performed using IBM® SPSS ® Statistical software (Version 19, IBM Corporation, Somers, New York, USA).

(a) Descriptive Statistics: The means and standard deviations of peak force and time to peak were calculated over the 20 impacts. These values were recorded for each glove type (boxing vs. MMA) and used for comparison for response over time within each glove type and between glove types.

(b) Inferential Statistics: Inferential statistical analyses were performed to determine if any significant changes in peak force and time to peak over the testing period within each glove type and between gloves. A two way repeated measures ANOVA (time and glove type set as factors) was performed to compare outcome variables between each glove and to determine any significant

changes ($p < 0.05$) in impact response between gloves at each time point. A one way repeated measures ANOVA (time set as the single factor) was performed to compare outcome variables at each time point within each glove to determine any significant changes ($p < 0.05$) in impact characteristics over time. Assumptions of normality and homoscedasticity were made with this data. These statistical tests were performed on the absolute values of force (N) and time to peak force (ms). Comparison of change in peak force and time to peak force between glove types was also performed using a two way repeated measures ANOVA (time and glove type set as factors) but percent change between adjacent time periods was used as the measure between gloves as shown in Equation 1. This was repeated for all other time points (Time60 – Time30, Time90 – Time60, etc).

$$\%Change = \frac{(Time30 - Time0)}{Time30} \quad (Eq1)$$

3. Results

Peak forces were found to be significantly higher in the MMA glove (2416.57 ± 326.13 N at the start of the collection) compared to the boxing glove (553.45 ± 65.08 N at the start of the collection) ($p < 0.001$), and rate of loading significantly faster (4.63 ± 0.045 ms to peak force vs. 21.3 ± 0.64 ms in the MMA and boxing gloves respectively) ($p < 0.001$). This trend continued over the entire collection at each time point (Tables 1 and 2). Time histories showing the force-time characteristics illustrate the rise in peak force and rate of force development over the 5 hours of testing (Fig. 3 shows the boxing glove results while Fig. 4 shows MMA glove results). Figure 5 shows the rate of loss of impact attenuation as the boxing glove loses attenuation properties initially while the MMA glove retains this for more impact cycles.

Table 1. Summary of force-time data over 300 minute collection period for 16 oz boxing glove.

Number of Strikes	Peak Force (N)	Time to Peak (ms)
0	532.25 ± 65.08	21.30 ± 0.64
1,000	680.64 ± 80.55	21.30 ± 0.41
2,000	683.02 ± 114.83	19.91 ± 0.53*
3,000	725.58 ± 73.24*	20.37 ± 0.44
4,000	731.10 ± 68.61 *	19.91 ± 0.46
5,000	743.91 ± 76.11*	18.98 ± 0.43*
6,000	744.86 ± 93.31*	18.98 ± 0.28*
7,000	745.48 ± 42.44*	18.98 ± 0.33*
8,000	746.52 ± 91.56*	19.91 ± 0.49*
9,000	747.32 ± 62.61*	19.91 ± 0.33*
10,000	747.41 ± 59.75*	19.91 ± 0.59*

*Statistically significant difference from Time 0 ($p < 0.05$)

Table 2. Summary of force-time data over 300 minute collection period for 4 oz MMA glove.

Number of Strikes	Peak Force (N)	Time to Peak (ms)
0	2416.57 ± 326.13	4.63 ± 0.045
1,000	2479.99 ± 390.12	4.63 ± 0.051
2,000	2515.81 ± 313.16	4.17 ± 0.049*
3,000	2540.95 ± 328.24	4.17 ± 0.069*
4,000	2542.51 ± 274.33	3.70 ± 0.069*
5,000	2572.55 ± 314.43	4.17 ± 0.056*
6,000	2714.50 ± 356.11	4.17 ± 0.041*
7,000	2729.41 ± 410.67	3.70 ± 0.052*
8,000	2769.01 ± 396.69	4.17 ± 0.062*
9,000	3247.17 ± 332.53*	3.70 ± 0.047*
10,000	3671.70 ± 443.32*	2.78 ± 0.053*

*Statistically significant difference from Time 0 ($p < 0.05$)

Material fatigue affected kinetic properties of both gloves, though this effect was more pronounced in the MMA glove. Peak force experienced by the boxing glove rose by 25% throughout the trial (532.25 ± 65.08 N at the start compared with 747.41 ± 59.75 N at the end of the collection period) (Table 2), compared to a 35% increase experienced by the MMA glove (2416.57 ± 326.13 N vs. 3671.70 ± 443.32 N from the start to end of the collection) (Table 1). Similar trends were observed regarding rate of loading where a 32% change was measured in the boxing glove (21.30 ± 0.64 ms decreasing to 19.91 ± 0.59ms) and a 60% change in the MMA glove (4.63 ± 0.045 ms decreasing to 2.78 ± 0.053ms) over the duration of the collection. Though each glove experienced significant changes over the testing period (comparison of values at 0 strikes to 10,000 strikes yielded significant changes of $p < 0.05$ for both glove types), the rate of change between each time point varied between glove type (Fig. 5). The boxing glove experienced significant changes early in testing ($p < 0.05$) where increases in peak force relative to the initial value occurred at 3,000 strikes and beyond (Table 1). Contrasting this to the MMA glove, significant increases in peak force relative to the initial value was not experienced until after 9,000 strikes (Table 2). The change in load rate between time points did not occur at the same pace between gloves – the MMA glove experienced significantly faster load rates (compared to the initial load rate) starting after 2,000 strikes. However, the boxing glove experienced a significantly faster load rate compared to the initial rate after 2,000 strikes but no significant changes were found again until after 5,000 strikes.

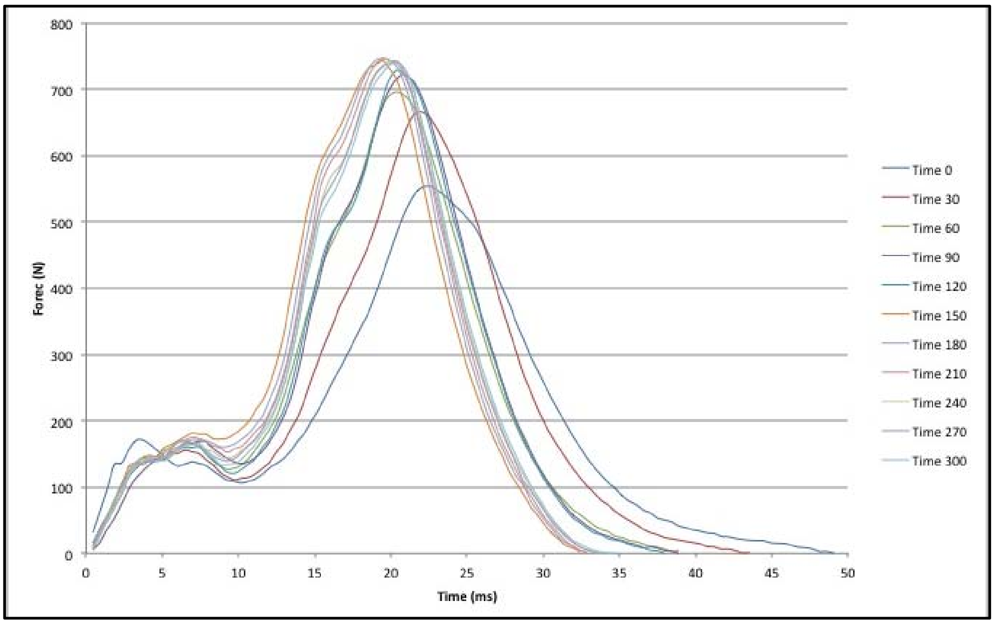

Figure 3. Summary of force-time history characteristics over 300 minute collection period for 16 oz boxing glove.

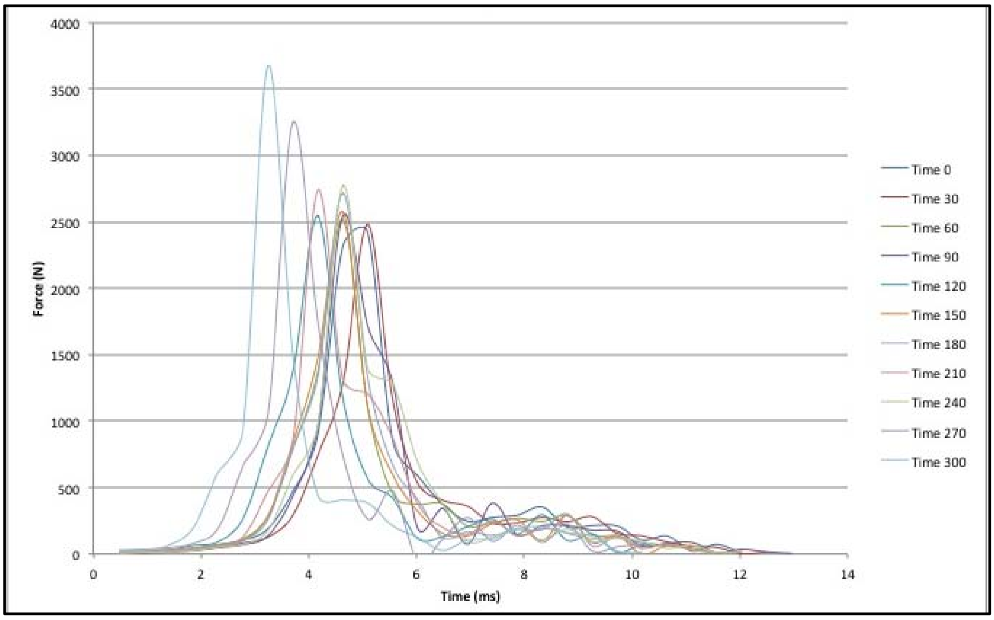

Figure 4. Summary of force-time history characteristics over 300 minute collection period for 4 oz MMA glove.

Comparing the impact characteristics between boxing and MMA gloves (Fig. 3 and 4), significant differences between gloves at each time sample were observed ($p < 0.001$) (Table 3). In general, peak forces produced by the MMA glove were 3.5-5 times greater than the boxing glove. Significant differences were also observed between rates of loading in which the MMA glove achieved peak force significantly faster than the boxing glove at all instances in time ($p < 0.001$)

(Table 3). Comparisons of percent change in force experienced between each time point between gloves revealed no significant changes except for near the beginning (0 to 1,000 strikes) and the end of collection (8,000 to 9,000 strikes) (Table 3). Similar analysis of changes in time to peak showed significant differences between gloves between 3,000-4,000, 4,000-5,000, 6,000-7,000, 7,000-8,000, 8,000-9,000, and 9,000-10,000 strikes (Table 3).

Table 3. Comparison of force time over 300 minute data collection between 16 oz boxing glove and 4 oz MMA glove.

Number of Strikes	Force difference between gloves (MMA-Boxing)(N)	Percent change force boxing [(T2-T1)/T2] (%)	Percent change force MMA [(T2-T1)/T2] (%)	Time difference between gloves (Boxing – MMA) (ms)	Percent change time boxing [(T2-T1)/T2] (%)	Percent change time MMA [(T2-T1)/T2] (%)
0	1882.07*	--	--	16.67*	--	--
1,000	1793.53*	.2180 ± .136**	.0242 ± .0648**	16.67*	-0.00557 ± .442	-0.00046 ± .0136
2,000	1833.72*	.0035 ± .208	.0169 ± .209	15.74*	-0.0659 ± .420**	-0.111 ± .0132**
3,000	1815.87*	.0587 ± .240	0.0097 ± 0.239	16.2*	0.0214 ± .0429	0.00094 ± .022
4,000	1812.23*	.0076 ± .148	.0007 ± .170	16.21*	-0.0237 ± .0256**	-0.123 ±.0339**
5,000	1831.95*	.0172 ± .156	.0126 ± .186	14.81*	-0.0495 ±.0386**	0.113 ± .0211**
6,000	1968.02*	.0013 ± .185	.0505 ± .145	14.81*	-0.00029 ± .0278	0.000166 ± .01
7,000	1983.77*	.0008 ± .130	.0060 ± .167	15.28*	-0.00055 ± .0274**	-0.129 ± .0214**
8,000	2020.98*	.0014 ± .151	.0138 ± .237	15.74*	0.0469 ± .0252**	0.114 ± .0165**
9,000	2624.89*	.0011 ± .134**	.1793 ± .224**	16.21*	-0.00096 ± .0377**	-0.129 ± .0268**
10,000	2945.14*	.0001 ± .144	.0868 ± .135	16.21*	-0.00063 ± .0314**	-0.328 ± .0364**

*Statistically significant difference ($p < 0.05$).
**Means with superscript denote statistically significant difference between gloves ($p < 0.05$).

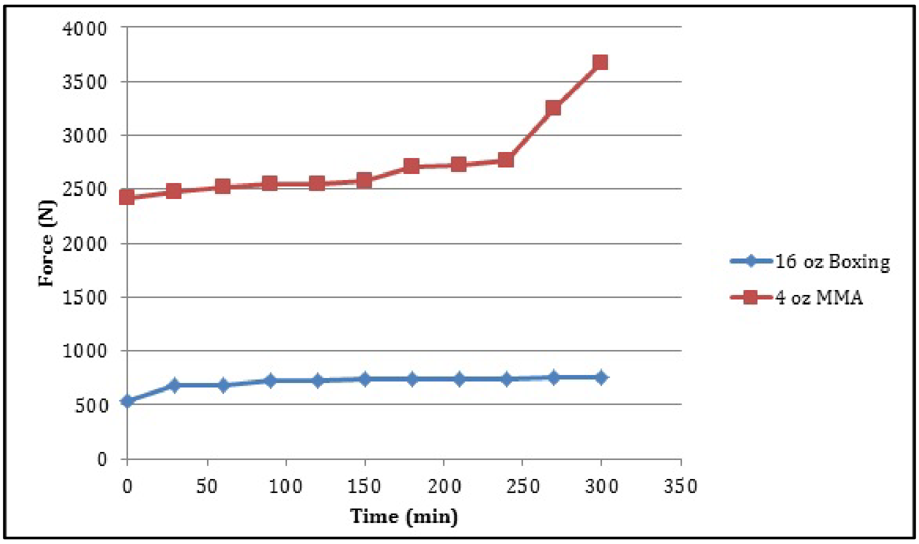

Figure 5. Difference in peak forces experienced by the 16 oz boxing glove and 4 oz MMA glove over the 5 hour data collection period. The magnitude and shape of this curve provides insight as to how deterioration of the glove material affects strike characteristics.

4. Discussion

Unique kinetic characteristics were observed between MMA and boxing gloves; MMA gloves experienced greater peak forces and quicker rates of loading. Thus, the first hypothesis is accepted. Both gloves showed evidence of material fatigue and deterioration, though the pattern of deterioration over time varied between the two gloves – the MMA glove retained the majority of its characteristics through the early stages of testing but variables varied greatly near the end of testing. The boxing glove showed an opposite effect where changes in properties were observed early on but stabilized as testing progressed. Thus the second hypothesis is accepted with some qualification.

4.1. Insight into Peak Force Attenuation

Higher peak forces experienced by the MMA glove may be solely attributed to the thinner and lighter padding layer over the knuckle portion of the glove, apparently from the reduced shock absorbing effect from the foam layer. Conversely the larger, heavier boxing glove is thought to create a larger damping effect due to a thicker layer of foam over the impact site. In order to obtain insight into this question additional testing on core foam samples was performed. It was observed that when samples of the same composition foam were tested with varying thicknesses the lowest peak forces were measured in the thickest samples (Fig. 6).

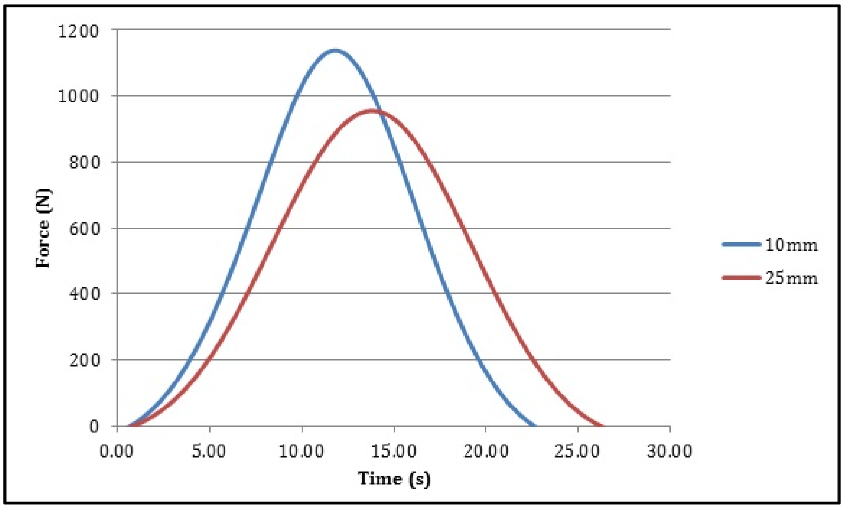

Figure 6. Comparison of kinetic properties of a core foam sample of varying thickness. Note how thicker foam absorbs impact to a greater degree resulting in lower peak force and slower load rate.

Material stiffness and deformation may also play a role in the peak force characteristics of the gloves – a stiffer material will deform less than lower stiffness foam. Smaller deformation is thought to result in less energy loss upon controlled impact which in turn leads to greater peak force. The tradeoff between stiffness, deformation and peak force is the fatigue characteristics over time. While decreasing stiffness may help lessen the force of the blow this is also mitigated by the thickness of the padding. If the padding layer is too thin this results in full compression and 'bottoming out' upon impact, allowing the much harder knuckles of the hand to make contact through the compressed padding layer, resulting in a sharp rise in force.

An interesting observation made during boxing glove tests was a dual peak force-time characteristic upon impact. An initial lower peak of force first occurred followed by a slight dip and secondary higher peak (Fig. 3). Similar observations were made in testing of layered core foam samples (Fig. 7). Researchers believe that the initial peak may be attributed to full deformation of the first foam layer, serving as a 'crush zone.' The absorption of impact energy then reduces peak amplitude of the second peak, attenuating peak force experienced during impact. This mechanism may serve to protect the user's hand by having an initial foam layer absorb energy.

4.2. Rate of Loading

Thinner padding resulted in quicker load rate (Table 3). This is consistent with results gathered by Smith (1987), and Smith and Hamill (1985). This observation was also made during testing of core foam samples where thicker padding resulted in a greater amount of time to reach peak force (Fig. 6). Inferences between the unique loading patterns between the two gloves and injury mechanism can be made. Stiffness properties of bone tissue alter with load rate; generally as load rate increases so does the modulus of elasticity (Einhorn, Azria, & Goldstein, 1992). Thus a strike made with an MMA glove may cause the athlete being struck to experience greater peak load, but due to higher load rate the risk of bone trauma or fracture may actually be decreased. The boxing glove, on the other hand, exposes the striking surface to a longer duration and slower impact giving bone time to deform and possibly fracture. These differences may have physiological implications to how tissues respond to load rate and magnitude which can be explored in future experiments.

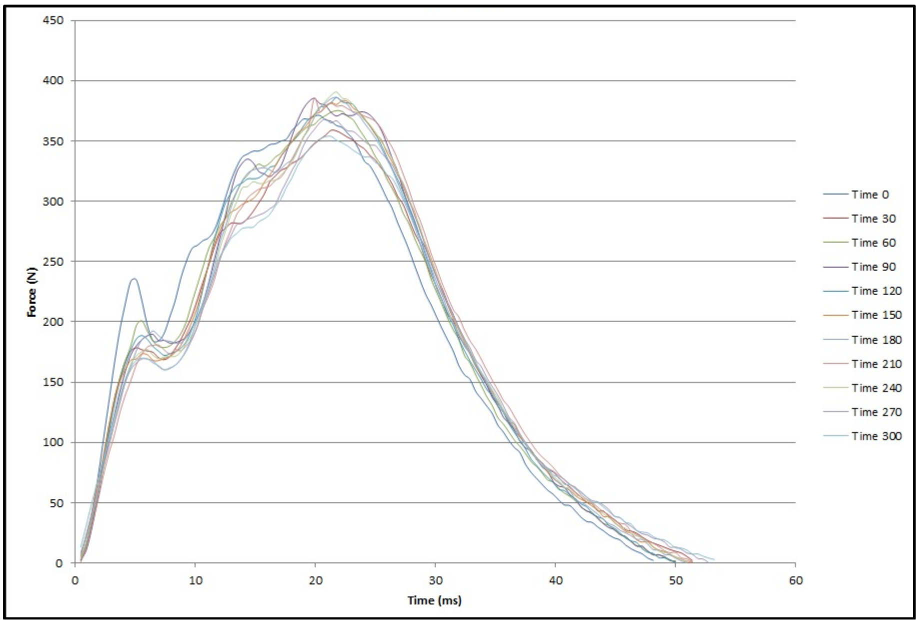

Figure 7. Force-time history of 'R6' foam core sample. This sample consisted of six 2 cm layers of mixed reclaimed foam. Note the dual peak response in which an initial smaller peak arises before a second larger peak.

4.3. Fatigue Life

The nature of the five hour test was intended to simulate continuous use of 10,000 strikes which would serve as a test of the long term impact characteristics. Both gloves showed signs of deterioration, evidenced by changes in kinetic properties and observed physical wear, though the changes in these characteristics varied between the glove types. Generally both gloves showed signs of material deterioration but this occurred early in testing (after 60 minutes) for the boxing gloves, and much later in testing (after 240 minutes) for the MMA gloves. The initial rise in peak force in the boxing gloves is thought to be due to a 'breaking in' period in which padding materials experienced some deterioration before settling and producing more consistent impacts. Contrasting this to the MMA glove kinetic properties remained relatively constant up to 5,000 impacts into testing before a gradual increase in peak force, followed by a larger increase in peak force after 8,000 impacts. The sharp rise in force after this milestone was thought to be due to the fatigue of material properties indicating that the MMA glove substantially deteriorated after 8,000 continuous impacts. This may be inferred to mean that the MMA glove was robust enough to maintain its initial characteristics after long term use before reaching a material failure point. In contrast, the boxing glove lost its initial ability to absorb force after 2,000 strikes but maintained relatively constant characteristics after that period. Insight to these findings would help users determine the lifespan of these gloves.

4.4. Limitations

Testing was performed in a single session. In real life the cumulative strikes occur over multiple training sessions with hours or days off between each session driving which glove materials can rest. Typical boxing training sessions would create multiple, variable-force impacts over one to two hours, and boxers in competitive bouts have been documented to create on average 9.4 impacts per round (bouts lasting up to 12 rounds) (Miele & Bailes, 2007). Thus, testing 10,000 continuous strikes over a 5 hour period may not accurately depict how these gloves would be used in real life scenarios.

5. Conclusion

The 4 oz MMA glove was found to have substantially different kinetic characteristics compared to the boxing glove, displaying much higher peak forces and faster time to reach peak force. Material properties such as thickness and stiffness alter these kinetic characteristics – generally thicker materials will allow for slower load rates and lower peak forces, as do less stiff materials. However, as deterioration becomes a factor with repeated loading parameters failure of less stiff materials may lead to higher peak forces and faster load rates. These changes in kinetic characteristics can be inferred to affect injury potential of blunt force trauma.

Both sports of MMA and boxing involve participants receiving extremely violent impacts from punches – the results of this experimentation show that MMA athletes potentially experience much higher impact forces but boxing athletes potentially experience greater contact time per punch.

Funding agencies

Hayabusa Fightwear

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Author's biographical data

Benjamin Lee (Canada), MSc holds a Masters degree in Spine Biomechanics from the University of Waterloo. His work has focused on answering biological questions associated with core training on torso stiffness; this work is directed towards understanding how core stiffness affects athletic performance, specifically striking based combat sports. Ben has applied his research in the physical training of numerous martial artists. E-mail: lee.bcy@gmail.com.

Stuart McGill (Canada), PhD is a professor of spine biomechanics at the University of Waterloo. His work has been directed toward understanding spine function and injury mechanisms, and using this as a foundation to develop rehabilitation and training approaches. As a consultant he has worked with elite athletes including martial artists. E-mail: mcgill@uwaterloo.ca.