

# Unique method for analysing pressure distribution across the knuckles during boxing

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**Objectives:** The hand is commonly injured in boxing but it is not clear why some athletes sustain hand injuries while others do not. It is possible that there are differences in the distribution of impact forces at the knuckle during punching between athletes and that certain distribution patterns may be predictive of increased injury risk. We developed a method of analysing the distribution of impact forces at the knuckle during punching using pressure film. Pressure film allows a calculation of the distribution and magnitude of pressure and force between any two surfaces that come into contact. **Methods:** Pressure film was inserted into the gloves of three male subjects prior to punching a stationary target. After each punch, the pressure film was removed and analysed to determine the distribution of the impact force during each punch across each of the four knuckles. Punches were repeated multiple times for each subject. The proportional distribution of the impact force during punches was compared between knuckles and within subjects. **Results:** The proportional distribution of the impact force exerted during punches was significantly different between knuckles and within subjects ( $p < 0.05$ ). Knuckle 2 displayed the largest proportion of impact forces while knuckle 3 displayed the smallest proportion of impact forces. **Conclusions:** Pressure film inserted into boxing gloves can be used to analyse the distribution of impact forces across the knuckles during punching. Further work is needed to confirm the reliability and validity of the technique and establish whether there is an association between the impact forces at the individual knuckles and hand injury risk during boxing.

# UNIQUE METHOD FOR ANALYSING PRESSURE DISTRIBUTION ACROSS THE KNUCKLES DURING BOXING

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## INTRODUCTION

Although many trials have reported that the greatest proportion of injuries in boxing occur to the head and face[1, 2, 3], a small number of studies have found that the upper extremity, particularly the hand, may be equally at risk[4,5]. Timm et al. retrospectively collected injury data in relation to amateur boxers from the Olympic training center in the US over a 15-year period and found that 25% of injuries occurred in the upper extremity[4]. Loosemore et al. found that the hand displays the greatest number of injuries by anatomical location in elite-level, amateur boxing[5]. However, most previous explorations have focused on head and face injury during boxing and few have performed any specific investigation into the upper extremity or hand.

In the only published investigation into the nature and causes of boxing hand injury, Noble assessed 100 consecutive boxing injuries to the hand in 86 boxers presenting either post-match or in the office of the South African Boxing Board of Control[6]. Noble divided the hand into three different areas: (A1) the thumb, including the scaphoid and carpometacarpal joint; (A2) the wrist, including both the bases of metacarpals 2 – 5 but excluding the parts included in section A1 for the thumb; and (A3) the fingers, comprising the phalanges and the remaining metacarpals, excluding the parts included in section A2 for the wrist. Noble reported that 39% of all injuries occurred in A1, 35% in A2, and 26% in A3. Of the 26% of all injuries occurring in A3, 12% involved painful hypertrophy of the metacarpophalangeal joint soft tissues and underlying extensor tendon (i.e. “boxer’s knuckle” injury), while 8% involved metacarpal fractures, both of which were deemed to have occurred subsequent to large impact forces.

Impact forces resulting from the punch of an elite boxer can be very large[7,8,9]. Smith et al. developed a boxing dynamometer by combining a tri-axial force measurement system and a

boxing manikin and used it to compare the maximal punching force of 7 elite, 8 intermediate and 8 novice boxers during straight punches. Maximal punching forces were 4,800, 3,722 and 2,381N for the rear hand in the elite, intermediate and novice groups, respectively[7]. Joch et al. similarly compared 24 elite, 23 national-level and 23 intermediate-level boxers and reported punch forces of 3,453, 3,023 and 2,932N, respectively[8]. Smith reported impact forces during straight punches in senior England international amateur boxers with the lead hand of 1,722 and 1,682N to the head and body, respectively, and punches with the rear hand of 2,643 and 2,646N to the head and body, respectively[9]. Smith also reported impact forces during hook punches with the lead hand of 2,412 and 2,414N to the head and body, respectively, and punches with the rear hand of 2,588 and 2,555N to the head and body, respectively[9]. Walilko et al. assessed punching force in 31 Olympic boxers using similar apparatus and found that punch forces ranged from 1,990 to 4,741N while the mean force was 3,427N[10]. Atha et al. recorded punch forces of 4,096N in a world-ranked heavyweight boxer during punches directed at a cylindrical, instrumented target[11]. It seems plausible that these impact forces that are borne mainly upon the knuckles are responsible for the serious hand injuries that have been reported in several case studies[12] and which have led to the term “boxer’s knuckle” becoming widely used[13]. However, whether it is purely the magnitude of these impact forces or whether the distribution of such impact forces during punching are of any importance is unclear. Moreover, there is currently no standard method for ascertaining the distribution of the impact forces across the knuckles during punching.

In order to better understand the aetiology of hand injuries in boxing, there is therefore a need to understand the nature and distribution of the impact forces during punching. Knowledge of how such impact forces differ between athletes and whether any specific profile of force distribution is associated with increased injury risk will help inform successful injury prevention interventions. Therefore, we have developed a way of analysing the distribution of forces at the knuckles during punching using a unique method involving a specific type of pressure film.

## METHODS

Ethics approval was obtained through the Department for Health Research Ethics Approval Committee for Health (REACH) at The University of Bath. Written consent was obtained from the volunteers used.

The subjects comprised 2 male members of medical staff associated with the GB boxing squad and 1 male boxer from the GB boxing squad. The raters were 3 male members of medical staff associated with the GB boxing squad. The procedure was explained in full to the subjects and raters. Ethical approval for the study was granted by the Department for Health Research Ethics Approval Committee for Health (REACH). Each subject performed multiple hand wraps, with and without a punch. The right hand was tested in all cases. The subjects wore two non-latex medical gloves on top of each other on the hand being tested. The fingers were cut off the gloves to ensure no movement of the glove when a fist was made. The two gloves were used to hold a piece of pressure film in place, with the film sandwiched between the two gloves and the pointed end placed distally on the finger. The two parts of the pressure film (A-film and C-film) were cut into tapered strips 7mm wide, 38mm long on the short side, and 42mm long on the long side. A tapered end was used in order to make locating the film easier. To ensure that the A-film and C-film remained together during punching trials, they were glued together at the proximal end using standard super glue, to avoid slippage of the two pieces of film. The film was placed over each MCP joint from the second to fifth digits. The film was located with the mid point over the MCP joint, over the extensor tendon (see Figure 1).



Figure 1 – The placement of the pressure film over the extensor tendon at the MCP joint, before wrapping of the hands with a competition wrap

After the placement of the film the hand were wrapped with adiBPO3 4.5m competition black webbing. The hands were wrapped in the same way for all punches and for all individuals (see Appendix A). After wrapping, the hand was carefully placed in a XL Everlast™ boxing glove. Next the individual was either asked to punch a foam pad dynamometer utilising a hook punch (punch group) or the glove was then taken off after 10 seconds (non-punch group). The punching group was instructed to attempt to connect squarely with the centre of the pad with the knuckles, with an attempt corresponding to 80% of maximal effort. This figure was believed to represent a trade-off between gathering information from a punch with high impact forces, while minimising the risk of injury to the individual. In both groups the boxing glove and the hand wrap were then carefully removed to expose the pressure film. The pressure film was removed, and the A-film and C-film separated. The A-film was discarded and the C-film was labelled with a letter to determine which finger the piece of film was from, and a number. The film was catalogued.

Low standard Fuji Film Pressurex® film was utilised to measure the pressure at each knuckle during each punch. Pressurex® is a film, which reveals the distribution and magnitude of pressure and load between any two surfaces which come into contact. Pressurex film has been used before to measure pressure on the human body[14]. This film

is thin (0.1016 – 0.2032mm) and it is able to bend and flex such that it can be used on curved surfaces like the knuckles of the hand. The film used was a two-sheet pressure film. Following preliminary trials with a range of pressure film types, the Low standard pressure film was chosen. The low film has a pressure range of 25 – 100kg/cm<sup>2</sup> and is composed of an A-film and a C-film. The A-film consists of a micro-encapsulated colour-forming material. The C-film is made of a base coated with colour developing material. In order for the film to function and create a pressure map, the rough sides of the film need to be placed together. When pressure is applied the micro-capsules are broken and the colour forming material reacts with the colour-developing material to develop a pressure map. The intensity of the colour corresponds with the amount of load imparted on the film (see Figure 1). Further details available: <http://www.fujifilm.com/products/prescale/prescalefilm/features/>

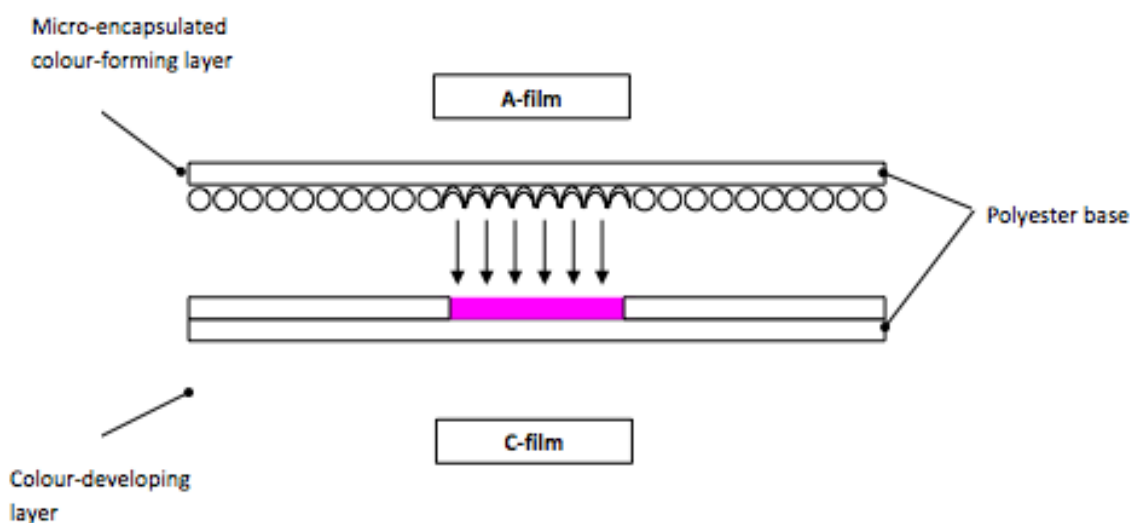


Figure 2 – Diagram showing how Pressurex® film works (adapted from FujiFilm)

In each trial, the pressure film was scanned using an Epson B300 scanner to create digital pressure maps. Following this, the scanned film was then analysed using Fuji film mapping distribution FPD-8010E software. This software converts the colour map into numerical load readings. An area measuring 4.5mm x 22mm was selected from the film corresponding to



the highest area of exposure. From the Pressurex® film the maximum load at each knuckle was then calculated for each punch, for each individual. The total load on the knuckles for each hand wrap, for each individual, was calculated by adding together the individual loads for the second to fifth knuckles of the hand. The proportion of this load accounted for by each knuckle was then calculated in order to determine how the load was distributed across the individual knuckles of the fist.

Pressurex® film has an operational range for temperature and humidity (Temperature: 20-35°C, humidity: 35-80%). To ensure the environment under the wrap is within the operational range, testing with a humidity and temperature sensor was undertaken. Utilising a HP22A handheld sensor, with an HC2-HP28 probe (accuracy  $\pm 0.5\%$  humidity, 0.1°C temperature) the temperature and humidity were measured a total of 9 times, in 3 subjects. The probe was placed at the superior aspect of the MCP joint, and the hand was wrapped and gloved using the same method as with pressure film. After a period of one minute, the temperature and humidity was recorded. The recorded readings were as follows: average temperature 30.5°C (range 28.7 – 32.2°C) and average humidity of 51.37% (range 46.1 – 54.9%). Ambient humidity and temperature at the time of recording were 51.5% and 19.9°C, respectively. The pressure film utilised is valid in the following ranges 20-35°C (higher for brief exposure) and 35-80% humidity. Even accounting for the accuracy of the probe, the environment under the wrap is inside the effective range of the pressure film.

Successful trials occurred where all procedures were followed correctly and where the pressure film was developed without being damaged. Where the raters deemed that the pressure film had been damaged during the process of removing it from its placement, the trial was discarded from the analysis.

### **Statistical methods**

All subject (name), attempt (number), rater details (name), and proportional knuckle impact forces as measured by the pressure film were entered into an Excel spreadsheet (Microsoft,

Seattle, USA). The impact forces for each knuckle were converted into a proportion for each trial and presented as a decimal fraction. All statistical tests and analysis were performed using R[15] by importing data directly from Excel. Shapiro-Wilks tests were performed to assess the normality of the data. Paired t-tests were used to compare mean impact forces between punch and no-punch conditions. One-way repeated measures analysis of variance (ANOVA) was used to assess for differences in the mean proportional knuckle impact forces for the punches between knuckles and within subjects. Adjusted paired t-tests using the Bonferroni correction were used to perform multiple comparisons between individual knuckles and within subjects where an overall difference was identified. Significance was accepted at  $p \leq 0.05$  for all comparisons.

## RESULTS

### *Number of successful trials*

There were 32 successful trials performed for each subject for the punch condition. The number of successful trials for the no-punch condition differed between the three subjects and was 24 for subject 1, 22 for subject 2 and 14 for subject 3.

### *Knuckle impact forces – between punching conditions*

Paired t-tests revealed that there was a significant difference ( $p \leq 0.05$ ) between the mean impact force recorded by the pressure film for all 3 subjects during the punch condition ( $352.1 \pm 158.2\text{N}$ ) and the mean impact force recorded by the pressure film for the non-punch condition was ( $121.0 \pm 80.0\text{N}$ ) (Figure 3).

### Total load across all knuckles recorded by pressure film in punch and no-punch conditions

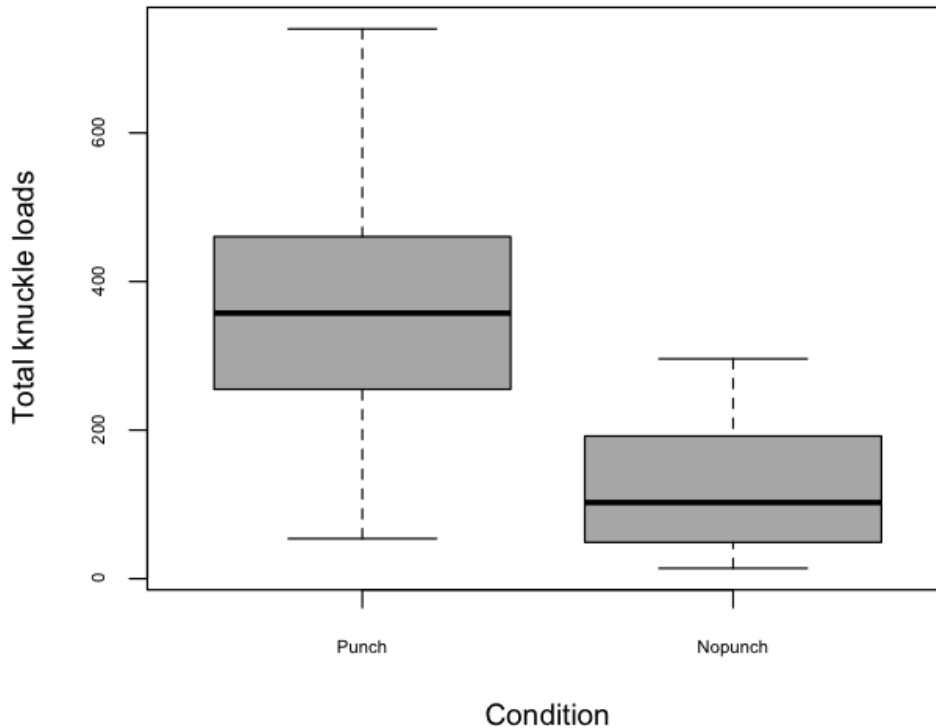


Figure 3 – Total impact forces during punch and no-punch conditions

#### *Proportional knuckle impact forces – between knuckles and within subjects*

In the punch condition, one-way repeated measures ANOVA revealed significant differences in the proportional knuckle impact forces for the punches between knuckles and within subjects ( $p \leq 0.05$ ). The mean  $\pm$  standard deviation of the proportional impact forces for knuckles 1 – 4 for all subjects together and expressed as decimal fractions were  $0.295 \pm 0.116$ ,  $0.378 \pm 0.101$ ,  $0.128 \pm 0.078$ , and  $0.201 \pm 0.078$ , respectively. In our group of subjects, knuckle 2 displayed the largest proportion of impact forces and knuckle 3 the smallest. Adjusted paired t-tests using the Bonferroni correction for multiple comparisons revealed that the differences between knuckles and within subjects were significant for all pairwise comparisons of knuckles ( $p \leq 0.05$ ). (Figure 4).

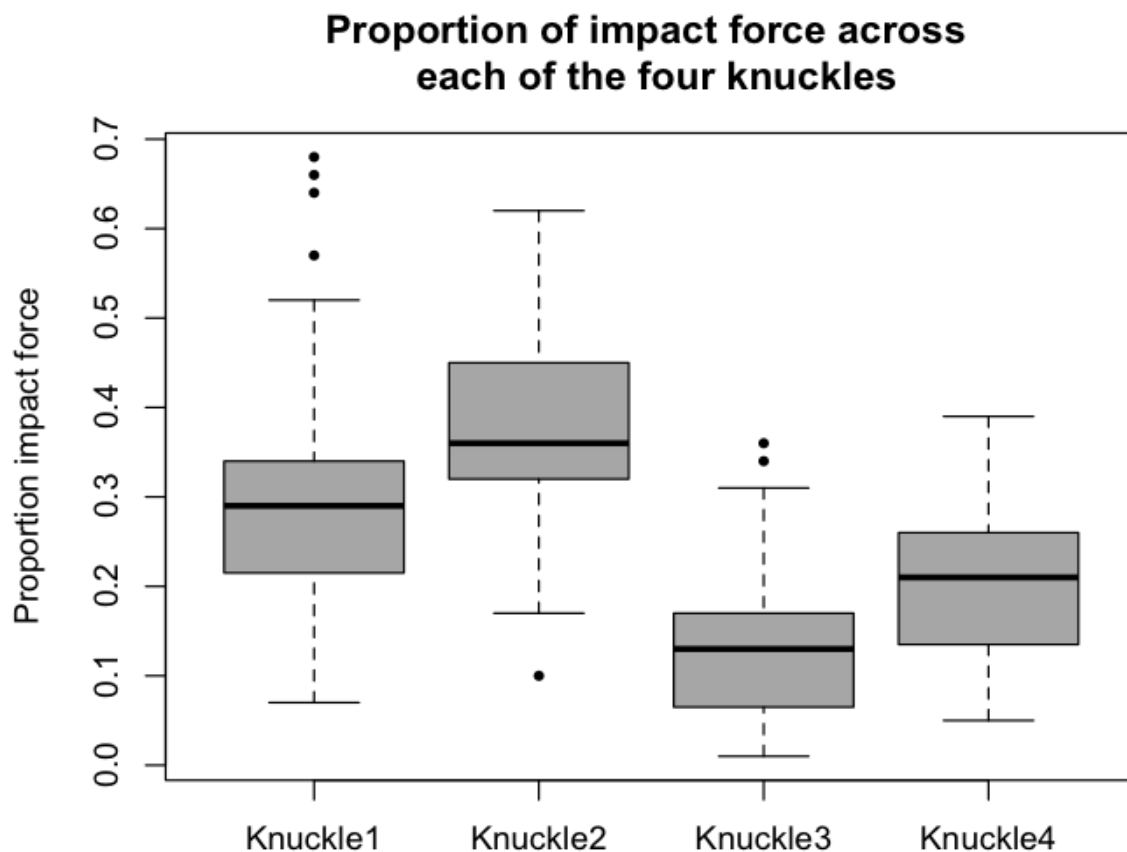


Figure 4 – Proportion of punching impact forces at each knuckle

## DISCUSSION

The results of this study demonstrate that this unique method of using pressure film can (1) differentiate between the impact forces displayed during punching and no punching, and (2) differentiate between the impact forces displayed at individual knuckles and within subjects. In this sample of subjects, knuckle 2 displayed the largest proportion of impact forces and knuckle 3 the smallest.

This unique method may therefore prove useful for exploring the mechanisms of hand injury in boxing. Certain distributions of impact forces across the knuckles could be predictive of hand injury risk, either because they are associated with a particular hand anatomy or because they reflect a certain punching technique. Identifying which knuckles are subject to the greatest impact forces in a particular athlete may prove to predict which knuckle is most

likely to be damaged, should a hand injury be sustained. If future research finds that knuckle impact forces are associated with increased injury risk, this technique could prove useful for devising tailored injury prevention methods, such as hand-wrapping techniques that place more padding over the knuckle that is most at risk.

Currently, the risk factors for hand injury in boxing are unclear. Hand injury risk in boxing could feasibly be affected by a multitude of different factors, including the magnitude of the punching impact forces, the distribution of these impact forces across the individual knuckles, or by the technique used during punching. Which of these factors is the most important, whether they interact with one another, and whether other factors are relevant, is unknown, as no previous trials have assessed the association between any of these individual factors and hand injury in boxers, either retrospectively or prospectively.

Previous studies have reported that the magnitude of impact forces can differentiate between boxers of elite, intermediate and novice groups[7] and between elite, national-level and intermediate-level boxers[8], respectively. Boxers of higher levels consistently display greater impact forces during punching than boxers of lower levels. However, such studies have primarily been concerned with the effect on the head following punching, for example by determining the risk of head injury associated with the acceleration resulting from a punching impact[10]. Since impact forces differ markedly between boxers of different levels, inferences might be drawn from studies that have compared overall injury rate during competition (when boxing wraps are at their thinnest and hand injury risk is greatest[5]) in amateur and professional boxers. It might be expected that elite and professional boxers boxing in competition might incur more hand injuries than less-skilled athletes boxing in competition. In this regard, Zazryn et al. found that the rate of injury was slightly greater in amateur boxers compared to professional boxers (1,221.4 vs. 1,081.1 injuries per 1,000 hours[16]). However, the injuries reported in this study were almost exclusively to the head and therefore it is not possible to draw any conclusions based on these data.

Although no previous studies have assessed the distribution of impact forces during punching, several previous trials have measured centres of pressure during walking. In this

respect, it is interesting to note that differences in the distribution of pressure on the underside of the foot during walking have been observed when walking barefoot compared to walking in shoes[17]. Grundy et al. reported that when walking barefoot there was a clear pattern for the centres of pressure to track a straight line down the middle of the foot before curving inwards to the big toe. On the other hand, when wearing shoes, the line ran straight down the whole foot without curving toward the big toe[17]. Thus, it seems that the use of a covering over the foot affects the distribution of pressure during impact loading. Whether the hand wrappings used during boxing similarly affect the proportion of impact forces at each knuckle, however, is unclear. Historically, in amateur boxing competition, only a limited length of hand bandaging has been allowed (up to 2.5m of crepe bandage)[5]. In training longer wraps, foam padding and tape are used to protect the hands more thoroughly. It may therefore be the case that differences in respect of hand wrappings alter the distribution of impact forces during punching. If this is the case, then this could be a mechanism by which a larger proportion of hand injuries are observed during competition when wrappings are different from during training[5].

The effect of punching technique on hand injury risk has not been directly assessed. However, Davis et al.[18] did observe differences in techniques used for punching between winners and losers during boxing competition. They noted that winners displayed a greater number of lead-hand combinations in round 1, a greater number of body-head, double-punch, and four-or-more-punch combinations in rounds 1 and 3, a greater number of triple-punch combinations in rounds 1 and 2, and a greater number of total combinations and block and counterpunch combinations over all 3 rounds than losers. Davis et al. drew the conclusion that winners achieve their greater scores by means of throwing punches in combinations. Whether these differences have any influence on injury risk, however, is unclear. Bledsoe et al.[2] did find that the risk of injury for losers was nearly twice the risk for the winners in a sample of male and female professional boxers in the US. This may suggest that some aspect of technique that differs between winners and losers during the dynamics

of a single fight influences the risk of injury. Whether hand injury in particular was affected by winning or losing in this trial, however, was unclear.

The study was limited primarily in that no external measurement of the impact forces was made. Thus, while the pressure film has been used by other researchers to calculate impact forces on other parts of the human body[14], the absolute force displayed at the hand measured by the pressure film was not validated. The study was also limited in that no measurement of reliability was performed between punches by each subject. Similarly, the reliability of the same punch by different raters was not assessed. Moreover, there are several factors that may have influenced the results that were not controlled. Firstly, it is unclear to what extent the proportion of impact forces at each knuckle might be affected by the external punch force. It may be the case that greater overall impact forces are associated with a specific distribution of impact forces across the knuckle, perhaps as a result of a particular punching technique or because of greater deformation of the glove or of the target. Secondly, no attempt to differentiate between boxers of different abilities was performed and it is possible that more experienced boxers might display a different pattern in relation to the proportion of impact forces at each knuckle compared to inexperienced boxers. Thirdly, no measurement of knuckle anatomy was performed and therefore it is unclear whether the specific profile of knuckle loads is related to any particular anatomical features. Fourthly, no assessment of punching kinematics was carried out and technique was not controlled, thus making it hard to assess whether punching technique is of any importance in affecting the distribution of impact forces. Finally, it is important to note that it still remains unclear whether there is any prospective or retrospective association between proportion of impact forces at each knuckle and increased risk of injury, either in total or at specific knuckles.

In conclusion, pressure film can be used to provide a measurement of the distribution of impact forces across the knuckles of an individual during punching. Further work is needed to confirm the validity and reliability of the technique. Additional research may also be useful in order to assess whether there is any association between the distribution of impact forces

across the knuckles during punching and individual hand anatomy, and between the distribution of impact forces across the knuckles during punching and overall hand injury risk in boxing.



## **ACKNOWLEDGEMENTS**

British Amateur Boxing Association, English Institute of Sport.

## **COMPETING INTERESTS**

None

## **FUNDING**

None

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## APPENDIX A

### ***Procedure for wrapping and gloving the hands:***

1. Ensure then hands are clean and dry and check the wrap is adequate
2. Place the loop around the thumb
3. Start by wrapping across the back of hand and do three rotations of the wrist.
4. Cross the back of the hand to wrap the knuckles starting from the fifth finger.
5. Perform three rotations of the knuckles
6. Cross the back of the hand (forming an X with the wrap)
7. Perform one complete wrap of the wrist
8. Wrap the thumb once
9. Wrap the wrist once more thus securing the thumb
10. Starting with the space between the fourth and fifth finger, wrap in between the fingers. In between wraps of the fingers wrap the wrist once
11. Wrap the wrist once
12. Wrap across the back of hand to the knuckles
13. Wrap the knuckles three times
14. Wrap back across the hand creating an X
15. Complete the wrap by wrapping the rest of the webbing around the wrist and secure the Velcro fastening.
16. Place the hand in a boxing glove and ensure the glove is secured properly.

## FIGURE LEGENDS

Figure 1 – The placement of the pressure film over the extensor tendon at the MCP joint, before wrapping of the hands with a competition wrap

Figure 2 – Diagram showing how Pressurex® film works (adapted from FujiFilm)

Figure 3 – Total impact forces during punch and no-punch conditions

Figure 4 – Proportion of punching impact forces at each knuckle