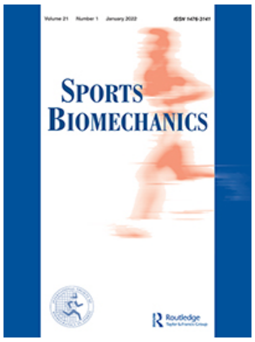
Quantifying wrist angular excursion on impact for Jab and Hook lead arm shots in boxing

GATT, Ian <http://orcid.org/0000-0001-9819-0807>, ALLEN, Thomas and WHEAT, Jonathan <http://orcid.org/0000-0002-1107-6452>



Routledge
Taylor & Francis Group

Sports Biomechanics

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/rspb20

Quantifying wrist angular excursion on impact for Jab and Hook lead arm shots in boxing

Ian Gatt, Thomas Allen & Jonathan Wheat

To cite this article: Ian Gatt, Thomas Allen & Jonathan Wheat (2021): Quantifying wrist angular excursion on impact for Jab and Hook lead arm shots in boxing, Sports Biomechanics, DOI: 10.1080/14763141.2021.2006296

To link to this article: https://doi.org/10.1080/14763141.2021.2006296

Published online: 06 Dec 2021.

SPORTS BIOMECHANICS
https://doi.org/10.1080/14763141.2021.2006296

Quantifying wrist angular excursion on impact for Jab and Hook lead arm shots in boxing

Ian Gatt[a,b], Thomas Allen[c] and Jonathan Wheat[b]

[a]Physiotherapy Department, English Institute of Sport, Manchester, United Kingdom of Great Britain and Northern Ireland; [b]Sport and Physical Activity Research Centre, Sheffield Hallam University, Sheffield, United Kingdom of Great Britain and Northern Ireland; [c]School of Engineering, Manchester Metropolitan University, Manchester, United Kingdom of Great Britain and Northern Ireland

ABSTRACT

The hand region is reported as the most common injury site in boxing, with more observed time loss than any other area in this sport. The amount of wrist motion, specifically flexion, has been described as contributing to these injuries, yet no literature is available to quantify wrist kinematics in boxing. This is the first paper describing wrist motion on impact in boxing. Utilising an electromagnetic tracking system, two types of shots were assessed, Jab (straight arm) and Hook (bent arm), during *in-vivo* testing procedures with 29 elite boxers. For both shots, flexion and ulnar deviation occurred concurrent on impact, with an M and SD of 9.3 ± 1.9° and 4.7 ± 1.2° respectively for Jab shots, and 5.5 ± 1.1° and 3.3 ± 1.1° respectively for Hook shots, supporting dart throwing motion at the wrist. For both Jab & Hook, wrist motion on impact occurred within >30% and >20% respectively of total available active range of motion, with wrist angles greater in both flexion (t = 9.0, p < 0.001, d = 1.7) and ulnar deviation (t = 8.4, p < 0.001, d = 1.6) for Jab compared to Hook shots. The study provides novel and quantifiable information regarding wrist kinematics during the impact phase of punching and potentially an improved understanding of injury mechanisms in boxing.

ARTICLE HISTORY
Received 14 April 2021
Accepted 9 November 2021

KEYWORDS
Boxing; wrist kinematics; dart throwing motion; electromagnetic tracking system; hand injuries

Introduction

In 1987, Noble (Noble, 1987) stated that if hyperflexion of the wrist occurred on impact in boxing it would injure the carpometacarpal joint of the hand. To date, no study has measured wrist motion in boxing. Flexion in the sagittal plane appears to be the only wrist movement considered on impact (Loosemore et al., 2017; Noble, 1987). Kinematic studies, however, describe a biplanar coupled motion occurring naturally in daily activities, described as dart-throwing motion of the wrist (Garcia-Elias et al., 1995; Ishikawa et al., 1999; Moritomo et al., 2004; Saffar & Semaan, 1994; Wolfe et al., 2006), rather than a uniaxial motion. Dart-throwing motion, involving an arc of motion from radial deviation and wrist extension to ulnar deviation and wrist flexion, occurs during many activities of daily living and sports (Fisk, 1980; Moritomo et al., 2004; Palmer et al., 1985; Sweeney et al., 2012). For example, Sweeney et al. (2012) observed that during the

CONTACT Ian Gatt ian.gatt@eis2win.co.uk

downswing in golf, both wrists experienced flexion and ulnar deviation. The dart-thrower's arc is described as the most stable and controllable plane of motion, representing the functional plane of wrist motion for most occupational and avocational activities (Garcia-Elias et al., 1995; Ishikawa et al., 1999; Moritomo et al., 2004; Saffar & Semaan, 1994; Wolfe et al., 2006).

In boxing, carpometacarpal instability of the hand has been identified as the most common injury, incurring the highest time loss from training (Loosemore et al., 2017; Loosemore, Lightfoot, Palmer-Green et al., 2015). As little movement occurs at the index and middle finger carpometacarpal joints (Morgan & Carrier, 2013), they are loaded when a punch is thrown correctly. Loading of the carpometacarpal joints is supported through investigations of proportional distribution of impact forces, using pressure films placed over the knuckles (Loosemore, Lightfoot, Meswania et al., 2015). The middle and ring finger knuckle displayed the largest and lowest proportion of impact forces, respectively (Loosemore, Lightfoot, Meswania et al., 2015). Higher force transmission towards the radial side of the wrist is supported by the literature, as observed when a load is applied to the hand using a rigid body spring model (Schuind et al., 1995). Index and middle finger carpometacarpal injuries are more common than those at the other fingers (Loosemore et al., 2017; McDougall, 1972; Melone et al., 2009; Nazarian et al., 2014). Concomitant avulsion of the tendons attaching at the base of the index and middle metacarpal joints, extensor carpi radialis longus and extensor carpi radialis brevis, respectively, are also identified from clinical practice (Mundell et al., 2014; Najefi et al., 2016; Turner et al., 2012). Extensor carpi radialis longus and extensor carpi radialis brevis muscles are typically described to perform combined extension with radial deviation of the wrist (Tanrıkulu et al., 2014), the opposing action of ulnoflexion motion. It is, therefore, proposed that as the hand contacts on the radial side during a punch, the wrist moves towards ulnoflexion, following the path described in dart-throwing motion.

While injuries at the hand can occur with both types of commonly used shot in boxing, Jabs (straight arm shots) appear to contribute more to carpometacarpal joint injuries than Hooks (bent arm shots) (Great Britain Boxing, 2020). This difference in injuries observed between straight and bent arm shots is possibly explained through the system of levers. Using standard terminology of levers (Bejnke, 2012), the hand would be the lever, the wrist tendons tension the effort, the wrist joint the fulcrum and the forces on impact the resistance. With a bent arm, the wrist tendons, which originate at the lateral epicondyle and therefore anatomically located proximal to the elbow joint, are under lower tension than with a straight arm indicating less effort required to maintain a stable wrist. Therefore, it is expected that straight arm shots exhibit more wrist angular excursion on impact than bent arm shots. Wrist angular excursion on impact is defined as the range of motion (ROM) taking place at the wrist joint from initial contact, between the boxer's glove and the training equipment (boxing bag), to its maximal angular displacement.

To understand the causes of injuries at the hand in boxing, knowledge of the wrist kinematics during the impact phase of punching is required. Studies investigating the kinematics of boxing have quantified movement occurring at the shoulder and elbow joints, but not the wrist (Bingul et al., 2018; Cheraghi et al., 2014; Dinu et al., 2020; Fisk, 1980; Noble, 1987; Piorkowski et al., 2011; Saffar & Semaan, 1994; Stanley et al., 2018; Sweeney et al., 2012; Whiting et al., 1988). Here, we assessed wrist motion on impact during straight and bent arm shots. We hypothesised that (a) ulnoflexion motion occurs in both Jab and Hook shots, (b) we could identify the amount of wrist angular excursion on impact for both Jab and Hook shots and (c) more wrist angular excursion on impact occurs in Jab than for Hook shots.

Method

Participants

To determine sample size, we conducted a priori power analysis using GPower 3.1.9.4 with power ($1 - \beta$) set at 0.80 and $\alpha = 0.05$, two-tailed. This analysis showed us a sample size of N = 24. To be in the study, participants had to be elite boxers, with no upper extremity symptoms and no history of upper extremity injury in the recent 3 months. Participants were recruited from both genders, as there were no studies supporting wrist kinematics or injury variations among male and female boxers. Participants (23 male, 6 female) were recruited from the Great Britain National Olympic Squad, which is ranked as one of the top teams in Olympic boxing (AIBA, 2020). Characteristics (M ± SD) were as follows: age 24 ± 4 years (range: 19–34 years), stature 178 ± 10 cm (range: 160–198 cm) and mass 71 ± 17 kg (range: 50–114 kg). All participants were right-arm dominant and orthodox stance boxers (left-hand leading). The movements and experimental protocol were explained verbally. All participants received written information about the study and provided informed consent before testing. The study protocols were approved by localResearch Ethics Committee (Ref No HWB-S&E-42).

Experimental design

To measure wrist excursion on impact, similar equipment and technique to a previous study was used showing good accuracy (<0.2° for flexion–extension with surrogate testing and <6° for flexion-extension and ulnar-radial deviations in the quasi-static testing) and good to substantial reliability for Jab and Hook shots (ICCs >0.8 for flexion–extension and ICCs >0.6 for ulnar-radial deviation) (Gatt et al., 2019). Custom-written software based on the Polhemus software development kit (Polhemus, Colchester, VT, USA) was used to record 6-degree-of-freedom (DoF) position and orientation data from three receivers and a digital stylus at 240 Hz. The system was calibrated according to manufacturer instructions. Further, during the pilot testing, metal distortion was investigated with using both static and dynamic testing, with no distortion identified.

Testing procedures

The electromagnetic tracking system receivers were fixed to the left upper limb (Figure 1) following the procedure of a previous study (Gatt et al., 2019). Each participant was asked to throw Jab and Hook shots with their lead arm. Jab shots were performed six times, allowing a break of about 3 s between shots. The same procedure was repeated for Hook shots in the same session. Before the punch testing, total wrist active ROM was measured using similar equipment and technique (quasi-static ROM testing) to a previous study (Gatt et al., 2019),

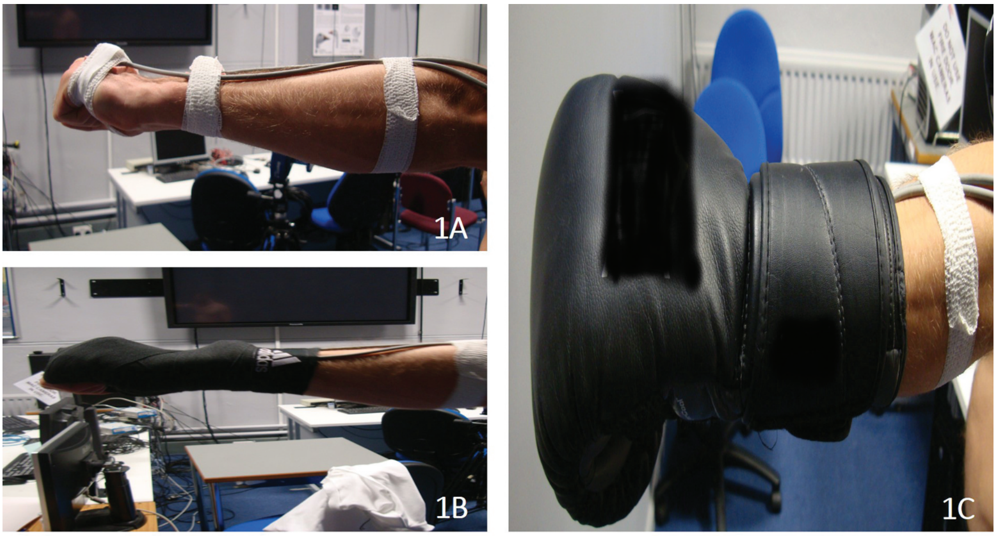


Figure 1. Electromagnetic tracking system receiver placement (a) on the hand and forearm for the quasi-static, (b) with a standard bandage technique covering the receivers, and (c) with a boxing glove covering the standard bandage technique and receivers for the punch testing.

allowing for wrist angular excursion on impact to be quantified as a percentage of total wrist active ROM. The participant was asked to fully flex a closed fist, holding onto a cylindrical plastic handle to mimic the functional position of a boxer's hand when held in a glove. The fully flexed position was held for three seconds, the wrist was then extended, and the new position was held for a further 3 s. For ulnar and radial deviation, the same procedure was used but with the forearm positioned in mid-pronation. All motions were performed three times and the mean range of motion was calculated.

Measurement equipment

The tracking system data from all testing procedures were processed using Visual 3D v3.79 (C-Motion, Germantown, MD, USA). Following a comparable protocol to previous studies, marker trajectories were filtered using a lowpass fourth-order zero-lag Butterworth filter in Visual 3D, using 10 Hz as the cut-off frequency (Gatt et al., 2019; Schmitz et al., 2014). The body-fixed reference frames were then constructed using the positions of anatomical landmarks identified with the digital stylus during a static calibration trial; Hand, Forearm and Arm, defined previously (Gatt et al., 2019). The anatomical landmarks were *Hand*; Head of second Metacarpal Bone, Base of second Metacarpal Bone, Head of fifth Metacarpal Bone, Base of fifth Metacarpal bone, *Forearm*; Styloid Process of Radius, 7 cm proximal to Styloid process of Radius, Head of Ulna, 7 cm proximal to Head of Ulna, and *Arm*; Medial Epicondyle of Humerus, Lateral Epicondyle of Humerus, Mid-Acromion of Scapula (Gatt et al., 2019). Segment coordinate systems were embedded in the left upper limb segments (Figure 2), defined based on the location of the anatomical markers such that the x-, y- and z-axis were medio-lateral, anterio-posterior and longitudinal respectively. The filtered trajectories

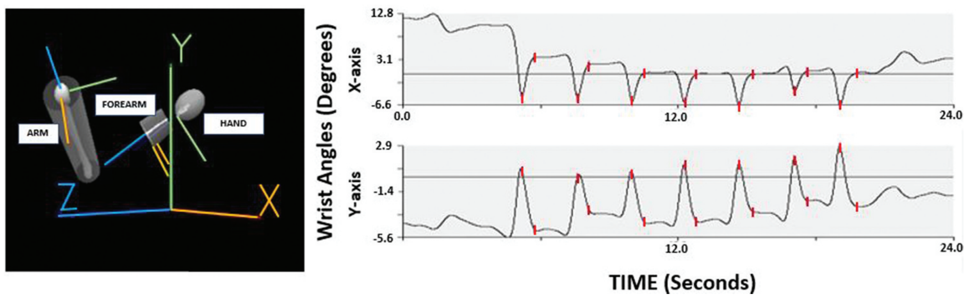


Figure 2. On the left, computer generated model for the punch testing in Visual 3D Software with xyz rotation sequence showing individual anatomical segments; arm, forearm, hand. On the right, flexion-extension (x-axis) and ulnar-radial deviations (y-axis) wrist angles with event markers (red) created for punch testing; Jab and Hook *(Figure amended and redistributed with permission from Gatt, Allen & Wheat, 2019 under the creative commons licencing agreement for open access funded publications).*

of the digital markers were used to compute the orientation of the distal segment relative to the proximal segment using Cardan angles (xyz rotation sequence) (Gatt et al., 2019; Grood et al., 1983). Positive and negative rotations around the x-axis were defined as flexion and extension respectively, and positive and negative rotations around the y-axis were defined as radial and ulnar deviation respectively.

For the punch testing, the wrist angle at impact with the bag was identified using a previously defined manual method (Gatt et al., 2019); (i) visual observation of the virtual upper limb (tested at 240 Hz) to identify the point of hand impact observed at terminal elbow extension combined with terminal shoulder flexion, (ii) movement at the x-axis and y-axis aligned together with displacement observed to occur simultaneously at the perceived point of hand impact and (iii) movement at the x-axis aligned with acceleration of the wrist with the maximum acceleration observed to occur simultaneously with maximum x-axis displacement.

Statistical analyses

Z-Scores for skewness and kurtosis were used to test for normal distribution of data with the threshold for the observed values set at ±2 SD of the predicted values. Differences between angular excursions of flexion and ulnar deviation for Jab or Hook shots, or between different Jab and Hook shots for the same angular excursion of flexion or ulnar deviation, were analysed using a two-tailed *t*-test ($\alpha = 0.05$). All data are presented as M ± SD. The magnitude of any differences (effect size) was assessed using Cohen's *d* with the following benchmarks; *small* (0.20), *medium* (0.50), *large* (0.8) and *very large* (1.3) (Sullivan & Feinn, 2012).

Results

All data for Jab and Hook shots were normally distributed with 95% of the observations falling inside the predicted *Z*-Scores.

For Jab shots, wrist angular excursions occurred concurrent in flexion and ulnar deviation, with a mean of 9.3 ± 2.0° and 4.7 ± 1.2°, respectively (Table 1). Wrist angular excursions were greater (t = 10.3, $p < 0.001$, d = 1.9) for flexion than ulnar deviation. Wrist angular excursions represented 17.2 ± 4.3% and 18.3 ± 8.0% of the total active wrist ROM for flexion and ulnar deviation, respectively (Table 2). All wrist angular excursions on impact were under 30% of the total wrist active ROM.

For Hook shots, wrist angular excursions on impact, occurred concurrent in flexion and ulnar deviation, with a mean of 5.5 ± 1.1° and 3.3 ± 0.9°, respectively (Table 1). Wrist angular excursions were greater (t = 8.6, $p < 0.001$, d = 1.6) for flexion than ulnar deviation. Wrist angular excursions represented 10.4 ± 3.2% and 12.8 ± 6.3% of the total active wrist ROM for flexion and ulnar deviation, respectively (Table 2). All wrist angular excursions on impact were under 20% of the total wrist active ROM.

When comparing Jab and Hook shots, wrist angular excursions on impact were greater in both flexion (t = 9.0, $p < 0.001$, d = 1.7) and ulnar deviation (t = 8.4, $p < 0.001$, d = 1.6) for Jab than Hook shots. When expressed as a percentage of the total wrist active ROM, wrist angular excursions were also greater in both flexion (t = 6.9, $p < 0.001$, d = 1.3) and ulnar deviation (t = 4.9, $p < 0.001$, d = 0.9) for Jab than Hook shots.

Discussion and implications

This study quantified wrist motion in boxing, whereas others investigated the kinematics occurring at more proximal joints to the wrist in this sport (Bingul et al., 2018; Cheraghi et al., 2014; Dinu et al., 2020; Fisk, 1980; Noble, 1987; Piorkowski et al., 2011; Saffar & Semaan, 1994; Stanley et al., 2018; Sweeney et al., 2012; Whiting et al., 1988). The current study recruited elite boxers and used an electromagnetic tracking system, which was previously found to be accurate and reliable for both Jab and Hook shots (Gatt et al., 2019). The results identified ulnoflexion motion occurring in both Jab and Hook shots. All wrist angular excursions on impact occurred within 30% of the total wrist active ROM, quantified using a quasi-static active ROM before impact testing. Further, greater wrist angular excursions on impact occurred in Jab than Hook shots.

Table 1. Mean angles and 95% confidence intervals for the total wrist active ROM from the quasi-static ROM testing, and wrist angular excursions from the impact testing.

	Shot	Motion	ROM (degrees)	Std. Error Mean (degrees)	95% CI
Total active wrist ROM (quasi-static testing)		FLEX	55.3 ± 11.2	2.1	59.5–51.0
		EXT	70.1 ± 14.0	2.6	75.4.3–64.7
		UD	28.8 ± 9.4	1.7	32.3–25.2
		RD	18.8 ± 6.8	1.3	21.3.-16.2
Wrist angular excursions on impact (punch testing)	JAB	FLEX	9.3 ± 2.0	0.4	8.6–10.1
	JAB	UD	4.7 ± 1.2	0.2	4.2–5.2
	HOOK	FLEX	5.5 ± 1.1	0.2	5.1–5.9
	HOOK	UD	3.3 ± 0.9	0.2	2.9–3.6

FLEX, Flexion; EXT, extension; UD, ulnar deviation; RD, radial deviation.

Table 2. Mean angles and 95% confidence intervals for percentage wrist angular excursions (wrist angular excursions on impact expressed as a percentage of total active wrist ROM).

	Shot	Motion	ROM (%)	Std. Error Mean (%)	95% CI
% Wrist angular excursions on impact (Wrist angular excursions on impact expressed as a % of total wrist active ROM)	Jab	Flex	17.4 ± 4.3	0.8	15.7–19.0
	Jab	UD	18.3 ± 8.0	1.5	15.3–21.4
	Hook	Flex	10.4 ± 3.2	0.6	9.2–11.6
	Hook	UD	12.8 ± 6.3	1.2	10.4–15.2

FLEX, Flexion; EXT, extension; UD, ulnar deviation; RD, radial deviation.

Type of wrist motion occurring on impact for Jab and Hook shots

To date, flexion is the only wrist movement proposed on impact in boxing (Loosemore et al., 2017; Noble, 1987), with no study quantifying what type of wrist motion is occurring. In this current study, ulnar deviation occurred concurrent with flexion for both Jab and Hook shots. This agrees with other kinematic studies indicating that the dart-throwing motion of the wrist occurs in activities of daily living and other sports (Fisk, 1980; Li et al., 2005; Moritomo et al., 2004; Palmer et al., 1985; Sweeney et al., 2012).

The Extensor Carpi Radialis Longus and Extensor Carpi Radialis brevis muscles have been observed to perform eccentric and isometric contraction respectively during repetitive movements like pushing and turning a spring-loaded mechanism (Murgia et al., 2011), suggesting that on impact these muscles would function to limit the amount of ulnoflexion angular excursion. Further, the extensor carpi radialis longus and extensor carpi radialis brevis muscles are midcarpal supinators (Salva-Coll et al., 2011). Since the moment induced on impact would be ulnoflexion, the extensor carpi radialis longus and extensor carpi radialis brevis muscles would act to stabilise the wrist by inducing a radioextension torque to the wrist and therefore counteracting its natural tendency towards rotating into both flexion and ulnar deviation (Salva-Coll et al., 2011).

Boxers are instructed to make a fist before impact, which appears important as co-contraction of the muscles acting at the wrist is required to create stability at this joint (Salva-Coll et al., 2011). Further, maximal grip strength in normal healthy individuals has been observed to occur at 30–35° of wrist extension, with a substantial reduction in grip strength when deviation falls outside this range (Lee & Sechachalam, 2016; O'Driscoll et al., 1992). Since wrist extension is predominantly performed by the actions of extensor carpi radialis longus and extensor carpi radialis brevis muscles, it appears that limiting ulnoflexion could influence grip strength and therefore wrist stability on impact in boxing.

Amount of wrist angular excursion on impact for Jab and Hook shots

Before this study, no information was available on the amount of wrist angular excursion on impact in boxing. For both Jab and Hook shots, respectively, flexion was observed with a mean of 9.3 ± 2.0° and 5.5 ± 1.1°, whilst ulnar deviation was observed with a mean of 4.7 ± 1.2° and 3.3 ± 0.9°. This represented under 30% and 20% of the total wrist active ROM for Jab and Hook shots respectively. Conversely, activities of daily living can require up to 70% of the total wrist active ROM to complete the required tasks (Alford, 2020; Kim et al., 2014; Ryu et al., 1991). In other sports like basketball and golf, flexion has been observed with over 60° of the wrist active ROM (Ohnishi et al., 1992; Sweeney et al., 2012), indicating over 70% of the total wrist active ROM (Alford, 2020; Kim et al., 2014; Ryu et al., 1991).

In snowboarding (Greenwald et al., 2013) and skateboarding (Giddins & Giddin, 2020), near terminal wrist extension angular excursions have been recorded on impact during non-injurious falls. In these sports, the intention is to remain upright rather than impact through the wrist, which occurs as a protective mechanism when attempting to break a fall. The high wrist extension in snowboarding and skateboarding, therefore, indicates movements are 'forced' from the weight of the body over an open hand planted onto the ground. Conversely, in boxing the aim is to impact repetitively onto a target, using a 'controlled' wrist, with a closed fist. A stable wrist has been defined as one which, when loaded within a physiological range, does not deviate from a state of equilibrium at any point within the available ROM (Zdravkovic et al., 1995). In the current study, this state of equilibrium appeared to be under 30% of the total wrist active ROM for both shots.

Difference in wrist angular excursion on impact for Jab versus Hook shots

Wrist angular excursions on impact were greater in both flexion (t = 9.0, $p < 0.001$, d = 1.7) and ulnar deviation (t = 8.4, $p < 0.001$, d = 1.6) for Jab than Hook shots. Hook shots have, however, been observed to have higher fist velocities than straight punches (Piorkowski et al., 2011; Stanley et al., 2018; Whiting et al., 1988). This has been explained by more motion occurring at the shoulder joint than the elbow joint (Cheraghi et al., 2014; Dinu et al., 2020; Piorkowski et al., 2011; Stanley et al., 2018; Whiting et al., 1988), and that Hook shots also have a longer trajectory over which to accelerate (Piorkowski, 2009). With both higher velocity and impact forces in Hook shots (Lenetsky et al., 2013), more wrist movement could be expected to occur with Jab than Hook shots. Jab shots, however, do not exhibit a proximal-to-distal sequence due to fixed elbow positions with these punch types (Stanley et al., 2018). During Jab shots, the elbow joint straightens (extends) rapidly after the punching arm has begun accelerating towards the target, via angular velocities generated at the shoulder joint (Cheraghi et al., 2014; Jessop & Pain, 2016). Conversely during Hook shots, the elbow is fixed to an approximate right angle whilst the shoulder exhibits a rapid combination of movements, from beginning to contact, observed in the sequence of; abduction, flexion, protraction, and adduction (Piorkowski et al., 2011; Whiting et al., 1988). The current study demonstrates that more wrist angular excursion occurs during Jab shots, which are long levers and where the proximal joint (elbow) is mobile, compared to Hook shots which are shorter levers and where the elbow joint is maintained in a more stable position.

Limitations and strengths

There are some methodological aspects that should be addressed. First, the present study was performed solely on bags, which is one type of training method. Most hand injuries are recorded in competition (Loosemore et al., 2017). Considering the equipment used, wired and electromagnetic sensors, which can be affected by ferromagnetic materials disturbing the local magnetic field and therefore the position and orientation estimation (Roetenberg et al., 2007), makes it impractical for use in competition. Approximating competition, in training, is sparring. Similar, to competition however, the current wired equipment is impractical for use in sparring. For the use on bags, as performed in this study, wire placement was identified in pilot testing to ensure it did not restrict nor otherwise effect on participants movement. Further, the amount of wrist motion recorded in sparring, compared to competition and especially at the point when injuries occur, could still differ. Considerations towards the development of valid and reliable wireless equipment, which could be used to quantify wrist motion in both sparring and competition, is therefore warranted.

Another methodological aspect was the sequence of shots thrown by the participants, Jabs followed by Hooks. Randomisation of shots could have been considered, rather than a pre-selected sequence. Interestingly, however, more wrist motion occurred with the first type of shots thrown, Jabs, compared to Hooks, which eliminates the rationale of increased motion linked to potential fatigue. With the known low number of shots thrown, fatigue was not considered. Further, only the lead arm was chosen for testing as more shots are typically thrown with the lead arm than backhand. Since these were elite boxers participating in a full training environment, the authors were judicious on not impacting negatively on both performance and athlete health in their subsequent training sessions. Further studies could consider differences between lead and back hand. Finally, speed of movement (velocity) of the lead arm was not assessed. Greater wrist angular excursion occurring during Jab than Hook shots could have been due to differences in velocities, rather than lever systems. Hook shots have, however, shown higher velocities and impact forces than Jab shots (Lenetsky et al., 2013; Piorkowski et al., 2011; Stanley et al., 2018; Whiting et al., 1988).

The present study also had several strengths. First, we managed to recruit many participants, 29, from a National Olympic Squad, which is ranked as one of the top teams in Olympic boxing (AIBA, 2020). Second, all the boxers were tested in their training centre using familiar equipment and surroundings, improving ecological validity (Andrade, 2018). Finally, literature investigating the kinematics of boxing have quantified movement occurring at the shoulder and elbow joints, but not the wrist (Bingul et al., 2018; Cheraghi et al., 2014; Dinu et al., 2020; Fisk, 1980; Noble, 1987; Piorkowski et al., 2011; Saffar & Semaan, 1994; Stanley et al., 2018; Sweeney et al., 2012; Whiting et al., 1988). This therefore is the first studying quantifying wrist motion on impact in this, or any other combat sport.

Conclusions

This study demonstrates the novel and quantifiable effects of wrist kinematics on impact when throwing Jab and Hook shots on a commonly used type of training equipment. On impact both flexion and ulnar deviation occur, with more pronounced motion occurring with Jab than Hook shots. This study provides useful information on wrist kinematics during the impact phase of punching and potentially an improved understanding of injury mechanisms in boxing. Further research, however, is warranted to identify strategies that can influence the kinematics of the wrist on impact in boxing.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The author(s) reported there is no funding associated with the work featured in this article.

ORCID

Ian Gatt http://orcid.org/0000-0001-9819-0807
Jonathan Wheat http://orcid.org/0000-0002-1107-6452

References

AIBA. (2020). *AIBA world rankings 2020*. 24 January 2021.
Alford, S. L. (2020). Remote self-measurement of wrist range of motion performed on normal wrists by a minimally trained individual using the iPhone level application only demonstrated good reliability in measuring wrist flexion and extension. *Journal of Hand Therapy: Official Journal of the American Society of Hand Therapists*, *34*(4), 549–554 . https://doi.org/10.1016/j.jht.2020.05.001
Andrade, C. (2018). Internal, external, and ecological validity in research design, conduct, and evaluation. *Indian Journal of Psychological Medicine*, *40*(5), 498–499. https://doi.org/10.4103/IJPSYM.IJPSYM_334_18
Bejnke, R. S. (2012). *Kinetic Anatomy* (3rd eds). Human Kinetics.
Bingul, B. M., Bulgan, C., Tore, O., Bal, E., & Aydin, M. (2018). The effects of biomechanical factors to teach different Hook punch techniques in boxing and education strategies. *Journal of Education and Training Studies*, *6*(3a), 8–12. https://doi.org/10.11114/jets.v6i3a.3153
Cheraghi, M., Agha-Alinejad, H., Arshi, A. R., & Shirzad, E. (2014). Kinematics of straight right punch boxing. *Annals of Applied Sport Science*, *2*(2), 39–50. https://doi.org/10.18869/acadpub.aassjournal.2.2.39
Dinu, D., Milot, B., Slawinski, J., & Louis, J. (2020). An examination of the biomechanics of the cross, Hook and uppercut between two elite boxing groups. *Proceedings*, *49*(1), 1–6. https://doi.org/10.3390/proceedings2020049061
Fisk, G. R. (1980). La Biomecanique de l'articulation du poignet. In R. Tubiana (Ed.), *Traite de chirurgie de la Main* (pp. 171–176). Masson.
Garcia-Elias, M., Ribe, M., Rodriguez, J., Cots, M., & Casas, J. (1995). Influence of joint laxity on scaphoid kinematics. *Journal of Hand Surgery*, *20B*(3), 379–382. https://doi.org/10.1016/s0266-7681(05)80097-x
Gatt, I. T., Allen, T., & Wheat, J. (2019). Accuracy and repeatability of wrist joint angles in boxing using an electromagnetic tracking system. *Sports English*, *23*(2), 1–10. https://doi.org/10.1007/s12283-019-0313-6
Giddins, G., & Giddin, H. (2020). Wrist and hand postures when falling and description of the upper limb falling reflex. *Injury*, *52*(4), 869–876. https://doi.org/10.1016/j.injury.2020.11.056

Great Britain Boxing. Hand & wrist injury data 2013-2020. In: Great Britain Boxing iboxer software. 20 August 2020.

Greenwald, R. M., Simpson, F. H., & Michel, F. I. (2013). Wrist biomechanics during snowboard falls. *Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology*, *227*, 244–254. https://doi.org/10.1177/1754337113482706

Grood, E. S., Suntay, W. J., & Joint Coordinate, A. (1983). System for the clinical description of three-dimensional motions: application to the knee. *Journal of Biomechanical Engineering*, *105* (2), 136–144. https://doi.org/10.1115/1.3138397

Ishikawa, J., Cooney, W. P., 3rd, Niebur, G., An, K.N., Minami, A., & Kaneda, K. (1999). The effects of wrist distraction on carpal kinematics. *Journal of Hand Surgery*, *24A*(1), 113–120. https://doi.org/10.1053/jhsu.1999.jhsu24a0113

Jessop, D. M., & Pain, M. T. G. (2016). Maximum velocities in flexion and extension actions for sport. *Journal of Human Kinetics*, *50*(1), 37–44. https://doi.org/10.1515/hukin-2015-0139

Kim, T. S., Park, D. D., Lee, Y. B., Han, D. G., Shim, J. S., Lee, Y. J., & Kim, P. C. W. (2014). A study on the measurement of wrist motion range using the iPhone 4 gyroscope application. *Annals of Plastic Surgery*, *73*(2), 215–218. https://doi.org/10.1097/sap.0b013e31826eabfe

Lee, J. A., & Sechachalam, S. (2016). The effect of wrist position on grip endurance and grip strength. *The Journal of Hand Surgery*, *41*(10), 367–373. https://doi.org/10.1016/j.jhsa.2016.07.100

Lenetsky, S., Harris, N., & Brughelli, M. (2013). Assessment and contributors of punching forces in combat sports athletes: Implications for strength and conditioning. *Strength and Conditioning Journal*, *35*(2), 1–7. https://doi.org/10.1519/SSC.0b013e31828b6c12

Li, Z. M., Kuxhaus, L., Fisk, J. A., & Christophel, T.H. (2005). Coupling between wrist flexion-extension and radial-ulnar deviation. *Clinical Biomechanics*, *20*(2), 177–183. https://doi.org/10.1016/j.clinbiomech.2004.10.002

Loosemore, M., Lightfoot, J., Gatt, I., Hayton, M., & Beardsley, C. (2017). Hand and wrist injuries in elite boxing: A longitudinal prospective study (2005-2012) of the Great Britain Olympic Boxing Squad. *Hand*, *12*(2), 181–187. https://doi.org/10.1177/1558944716642756

Loosemore, M., Lightfoot, J., Meswania, J., & Beardsley, C. (2015). Unique method for analysing pressure distribution across the Knuckles during boxing. *PeerJ Preprints*, *3*, e917v1. https://doi.org/10.7287/PEERJ.PREPRINTS.917V1 .

Loosemore, M., Lightfoot, J., Palmer-Green, D., Gatt, I., Bilzon, J., & Beardsley, C. (2015). Boxing injury epidemiology in the Great Britain team: A 5-year surveillance study of medically diagnosed injury incidence and outcome. *British Journal of Sports Medicine*, *49*(17), 1100–1107. https://doi.org/10.1136/bjsports-2015-094755

McDougall, A. (1972). Hand injury in boxing. *British Journal of Sports Medicine*, *6*(2), 80–84. https://doi.org/10.1177/036354658701500408

Melone, C. P., Jr, Polatsch, D. B., & Beldner, S. (2009). Disabling hand injuries in boxing: Boxer's knuckle and traumatic carpal boss. *Clinics in Sports Medicine*, *28*(4), 609–621. https://doi.org/10.1016/j.csm.2009.06.004

Morgan, M. H., & Carrier, D. R. (2013). Protective buttressing of the human fist and the evolution of hominin hands. *The Journal of Experimental Biology*, *216*(pt 2), 236–244. https://doi.org/10.1242/jeb.075713

Moritomo, H., Murase, T., Goto, A., Oka, K., Sugamoto, K., & Yoshikawa, H. (2004). Capitate-based kinematics of the midcarpal joint during wrist radioulnar deviation: An in vivo three-dimensional motion analysis. *The Journal of Hand Surgery*, *29*(4), 668–675. https://doi.org/10.1016/j.jhsa.2004.04.010

Mundell, T., Miladore, N., & Ruiter, T. (2014). Extensor carpi radialis longus and brevis rupture in a boxer. *Eplasty*, *14*, ic40.

Murgia, A., Harwin, W., Prakoonwit, S., & Brownlow, H. (2011). Preliminary observations on the presence of sustained tendon strain and eccentric contractions of the wrist extensors during a common manual task: Implications for lateral epicondylitis. *Medical Engineering & Physics*, *33*(6), 793–797. https://doi.org/10.1016/j.medengphy.2011.02.002

Najefi, A., Jeyaseelan, L., Patel, A., Kapoor, A., & Auplish, S. (2016). Avulsion fractures at the base of the 2(nd) metacarpal due to the extensor carpi radialis longus tendon: A case report and review of the literature. *Archives of Trauma Research*, *5*(1), e32872. https://doi.org/10.5812/atr.32872

Nazarian, N., Page, R. S., Hoy, G. A., Hayton, M. J., & Loosemore, M. (2014). Combined joint fusion for index and middle carpometacarpal instability in elite boxers. *Journal of Hand Surgery European Volume*, *39*(3), 242–248. https://doi.org/10.1177/1753193413487469

Noble, C. (1987). Hand injuries in boxing. *The American Journal of Sports Medicine*, *15*(4), 342–346. https://doi.org/10.1177/036354658701500408

O'Driscoll, S. W., Horii, E., Ness, R., Cahalan, T. D., Richards, R. R., & An, K.-N. (1992). The relationship between wrist position, grasp size, and grip strength. *The Journal of Hand Surgery*, *17*(1), 169–177. https://doi.org/10.1016/0363-5023(92)90136-d

Ohnishi, N., Ryu, J., & Chung, I. S, Colbaugh, R., & Rowen, B. (1992). Analysis of wrist motion during basketball shooting. In R. Nakamura, R. L. Linscheid, and T. Miura (Eds.), *Wrist disorders* (pp. 49–55). Springer.

Palmer, A. K., Werner, F. W., Murphy, D., & Glisson, R. (1985). Functional wrist motion: A biomechanical study. *The Journal of Hand Surgery*, *10*(1), 39–46. https://doi.org/10.1016/s0363-5023(85)80246-x

Piorkowski, B. A. (2009). *Performance analysis of boxing: Biomechanical considerations in punching* [MPhil thesis]. John Moores University.

Piorkowski, B. A., Lees, A., & Barton, G. J. (2011). Single maximal versus combination punch kinematics. *Sports Biomechanics*, *10*(1), 1–11. https://doi.org/10.1080/14763141.2010.547590

Roetenberg, D., Baten, C. T. M., & Veltink, P. H. (2007). Estimating body segment orientation by applying inertial and magnetic sensing near ferromagnetic materials. *IEEE Transactions on Neural Systems and Rehabilitation*, *15*(3), 469–471. https://doi.org/10.1109/TNSRE.2007.903946

Ryu, J., Cooney, W. P., Askew, L. J., An, K.-N., & Chao, E. Y. S. (1991). Functional ranges of motion of the wrist joint. *The Journal of Hand Surgery*, *16*(3), 409–419. https://doi.org/10.1016/0363-5023(91)90006-w

Saffar, P., & Semaan, I. (1994). The study of the biomechanics of wrist movements in an oblique plain—a preliminary report. In F. Schuind, K. N. An, W. P. Cooney, & M. Garcia-Elias (Eds.), *Advances in the biomechanics of the hand and wrist* (pp. 305–311). Plenum Press.

Salva-Coll, G., Garcia-Elias, M., Leon-Lopez, M. T., Llusa-Perez, M., & Rodríguez-Baeza, A. (2011). Effects of forearm muscles on carpal stability. *Journal of Hand Surgery European Volume*, *36*(7), 553–559. https://doi.org/10.1177/1753193411407671

Schmitz, A., Ye, M., Shapiro, R., Yang, R., & Noehren, B. (2014). Accuracy and repeatability of joint angles measured using a single camera markerless motion capture system. *Journal of Biomechanics*, *47*(2), 587–591. https://doi.org/10.1016/j.jbiomech.2013.11.031

Schuind, F., Cooney, W. P., Linscheid, R. L., An, K. N., & Chao, E. Y. S. (1995). Force and pressure transmission through the normal wrist. A theoretical two-dimensional study in the posteroanterior plane. *Journal of Biomechanics*, *28*(5), 587–601. https://doi.org/10.1016/0021-9290(94)00093-j

Stanley, E., Thomson, E., Smith, G., & Lamb, K.L. (2018). An analysis of the three-dimensional kinetics and kinematics of maximal effort punches among amateur boxers. *International Journal of Performance Analysis in Sport*, *18*, 835–854. https://doi.org/10.1080/24748668.2018.1525651

Sullivan, G. M., & Feinn, R. (2012). Using effect size—or why the P value is not enough. *Journal of Graduate Medical Education*, *4*, 4279–4282. https://doi.org/10.4300/JGME-D-12-00156.1

Sweeney, M., Mills, P., & Mankad, A. (2012). Wrist kinematics during the golf drive from a bilaterally anatomical perspective. In L. Bradshaw, A. Burnett, and P. Hume (Eds.), *Proceedings of the 30th International Conference on Biomechanics in Sports* (pp. 92–95). International Society of Biomechanics in Sport.

Tanrıkulu, S., Bekmez, Ş., & Üzümcügil, A, & Leblebicioğlu, G. (2014). Anatomy and biomechanics of the wrist and hand. In M. Doral, and J. Karlsson (Eds.), *Sports injuries* (pp. 1–9). Heidelberg Springer.

Turner, S., Brewster, M. B. S., & Watson, J. S. (2012). Extensor carpi radialis longus avulsion: Presentation, treatment rationale and outcome of an unusual fracture. *Hand Therapy*, *17*(3), 73–76. https://doi.org/10.1258/ht.2012.012011

Whiting, W. C., Gregor, R. J., & Finerman, G. A. (1988). Kinematic analysis of human upper extremity movements in boxing. *The American Journal of Sports Medicine*, *16*(2), 130–136. https://doi.org/10.1177/036354658801600207

Wolfe, S. W., Crisco, J. J., Orr, C. M., & Marzke, M. W. (2006). The dart-throwing motion of the wrist: Is it unique to humans? *The Journal of Hand Surgery*, *31*(9), 1429–1437. https://doi.org/10.1016/j.jhsa.2006.08.010

Zdravkovic, V., Jacob, H. A. C., & Sennwald, G. R. (1995). Physical equilibrium of the normal wrist and its relation to clinically defined "instability". *The Journal of Hand Surgery, European Volume*, *20*(2), 159–164. https://doi.org/10.1016/s0266-7681(05)80043-9