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Biomechanical measurements of human impacts in basketball

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Abstract

Despite significant advances in materials and manufacturing techniques applied to sports protective equipment in recent years, sports injuries due to impact, contusions in particular, continue to occur. In this paper, a test methodology aimed at collecting data from laboratory-simulated human-on-human impacts in Basketball is presented. The study was executed in three stages with data being collected from: i) human on instrumented bag; ii) impactor on instrumented bag and iii) impactor on instrumented human impacts. In all cases, high-speed video and/or kinematic motion data capture systems were used to obtain parameters such as inbound/outbound velocities, contact durations while resistive ink technology pressure sensing films were used to estimate parameters such as pressure distributions, peak pressures, contact areas, impact forces. Elite-level athletes were used in all human trials to ensure that impact techniques and levels representative of the elite game were obtained and that tolerance to impacts was similarly representative. Two common strikes were simulated: knee on thigh and elbow on rib/torso. Five participants were used to collect the human-on-bag data while 12 participants were used to collect the impactor-on-human data. Between three and five impacts per scenario were performed to enable noise averaging and, importantly, likely injury-causing outlier capture.

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1. Introduction

Elite-level basketball has evolved in recent decades in particular in terms of its physicality and of the specialisation and fitness level of players. Comparison with players from the 1980’s will show increases in average height and mass which, when combined with greater physicality in gameplay, results in methods of mitigating impact-related injuries becoming a more pertinent consideration. The official basketball rules (FIBA, 2012) as approved by the Central Board of the international governing body, FIBA, state that: *“A foul is an infraction of the rules concerning illegal personal contact with an opponent…”*. Although basketball is therefore intended to be played in a non-contact manner, many accidental impacts occur and it is widely regarded among players as a contact sport.

A longitudinal study conducted by Dick et al. (2007) investigated the injury incidence amongst collegiate basketball players over a 16 year period. It was noted that the overall rate of injury occurrence during gameplay was 9.9 per 1000 athlete exposures which would suggest that players would suffer approximately one injury per season. Of those injuries, 76.6% were directly attributed to contact, just over two thirds of which occurred as a result of *contact* with other players. While injuries *not* (directly) related to contact, such as sprains and strains, were the most frequent, contusions accounted for a significant proportion of in-game injuries (≈ 10%).

While, in the study presented by Dick et al. (2007), contusion injuries were not significant in terms of “10+ Days of Activity Time Loss”, an indication of the potential impact of such injuries is provided by Diaz et al. (2003) who used imaging techniques to investigate the severity of quadriceps muscle contusions in athletes. A specific case report considered a blunt trauma experienced to the anterior thigh from a knee impact in basketball game play. The range of motion at the knee decreased by nearly 115% and the athlete suffered severe pain for the three days following the impact. Subsequent MRI scans revealed that it took up to 3.5 months for the athlete to fully recover, although he was able to resume play after three weeks.

The shift in the physiques of basketball players and the increased physical nature of the sport have elevated the prevalence and severity of in-game injuries with many players now opting to wear some form of personal protective equipment. Typically a set of protective undergarments, such as those shown in Fig. 1, are used: compression padded shorts (Fig. 1a) provide protection to the anterior and lateral thigh, the hip and the tailbone while a compression vest (Fig. 1b) provides protection to both the rib cage and the thoracic spine. The increased availability and uptake of such equipment has prompted the need to better understand the intensities of in-game impacts and usage scenarios to inform improved design and to understand its effectiveness. The aim of this study was, therefore, to experimentally investigate the kinematics and kinetics involved in common basketball impact scenarios with a view to providing a better understanding of the potential injury inducing phenomena experienced.

Fig. 1. Example (a) compression padded shorts; (b) compression vest commonly worn in elite basketball.

2. Methods

2.1. Test protocols & participants

Investigating the effect of human-on-human impacts experienced in basketball game play presents many logistical and ethical challenges. Even staged sports impacts in the laboratory environment (Halkon et al., 2012), due to the dynamic and relatively uncontrolled nature of the impacts, inevitably result in low experimental control, poor external validity or both. In order to overcome many of these limitations, a three-phased protocol was proposed:

- Human-on-Bag Impacts: the first phase involved five players, with playing experience at National League or better level, performing a series of basketball-relevant impacts on a "freely" suspended training bag instrumented as described in the following subsection. Age, mass and height statistics were 23.4 (2.9) years, 83.6 (12.4) kg and 194.3 (8.6) cm, respectively. Participants were asked to perform manoeuvres involving contact typical of those experienced or performed in practice or game scenarios. The kinematics and kinetics of the impact were recorded to provide an indication of the magnitudes experienced in basketball game play.

- Artificial Impactor-on-Bag Impacts: the second phase involved impacting the same instrumented bag used in the previous phase with a freely suspended artificial impactor. The advantage of the artificial impactor is that it provides a controlled, repeatable striking object that can be adjusted in terms of its mass, geometry and impact velocity to match both the contact areas and pressures experienced in the human-on-bag impacts. An iterative process presented the opportunity to determine a suitable artificial surrogate to be used in the third phase.

- Artificial Impactor-on-Human Impacts: this phase of testing involved impacting nine basketball players (20.9 (2) years, 88 (12.8) kg, 190.5 (6.8) cm), instrumented with pressure sensors fitted between the personal protective equipment and the body, using the artificial impactor developed in the second phase at increasing impact intensities up to a maximum level equivalent to that observed in the first phase. This final approach yields a more controllable method of applying the impacts at specific impact energies while ensuring that the participant does not experience extreme discomfort or a catastrophic injurious impact which may occur in less controllable human-on-human impacts. By adopting this increasing intensity approach, allowing the participant to withdraw at any time, strict ethical guidelines are adhered to and a level of external validity is maintained.

2.2. Instrumentation and other equipment

Pressure mapping, kinematic motion and high-speed video data capture were used to characterise the impact events.

Fig. 2. (a) 3001E F-Scan sensors; (b) laboratory layout; (c) schematic section view of training bag construction from top.

- Pressure mapping: a Tekscan F-Scan VersaTek system with 3001E Sport sensors, as shown in Fig. 2a, with pressure range 0-517 kPa (0-75 psi) was selected for this study based on its availability, low relative sensor cost and for reasons of obtaining data comparable with those obtained in a previous study (Halkon et al., 2012). Despite its intended application being that of quasi-static and lower-rate dynamic in-sole pressure measurements (e.g. gait analysis) the 750 Hz sample rate makes for a reasonable number of data points during the circa 200 ms impact event. The relatively dense (3.9 cm^{-2}) sensing element spacing (on a sensor active area of 107 x 305 mm; 954 elements in total) enables resolution of pressure variation across the impact region that is required to understand contusion occurrence mechanisms. The 0.15 mm sensor thickness, importantly, reduces the invasiveness on the participant in the human testing.

- Kinematic motion data capture: to determine the impactor velocity at impact, a Charnwood Dynamics 4x Codamotion cx1 system sampling at 800 Hz was employed, as can be seen in Fig. 2b. Active, infrared emitting markers were attached in clusters to the impactor bodies enabling, if required, 3 translational and 3 rotational degrees of freedom of motion to be determined.

- High-speed video data capture: a Photron Fastcam 675K-C1 camera was used to capture video data at between 500 Hz and 2 kHz depending up the impact type (i.e. human-on-bag, impactor-on-bag or impactor-on-human) and the nominal impact velocity. These data were also used to determine impact velocity in the absence of (reliable) Codamotion data. Video frame calibration for digitisation (Image Pro Analyser) was achieved by selecting an object of known length in the plane of the impact motion.

As shown in Fig. 2b, a 40 kg training bag with an additional 20 kg of sand was suspended from an A-frame. The suspension arrangement was specified in order that participants and the impactor could be readily brought into contact with the bag during the first and second phases, respectively. The mass of the bag was determined using anthropometric scaling parameters defined by Winter (1990) for a 100 kg individual; the head, neck and torso were included. The bag construction, as shown in Fig. 2c, includes a 50 mm thick polyethylene chip foam section surrounding the sand core. The resulting bag compliance is intended to represent that of human soft tissue. In the second phase the impactor was also suspended from the A-frame in order that the impact velocity, trajectory and location could be carefully controlled. In the third phase, the bag was replaced with the participant(s).

3. Results

Example impacts and pressure data for the human-on-bag tests are shown in Fig. 3 in which it can be seen that the impact region is typically not a continuous region of sensed pressure. Furthermore, due to its in-plane stiffness, the sensor has a tendency to crinkle when the sensor/surface is subjected to a relatively small diameter impact.

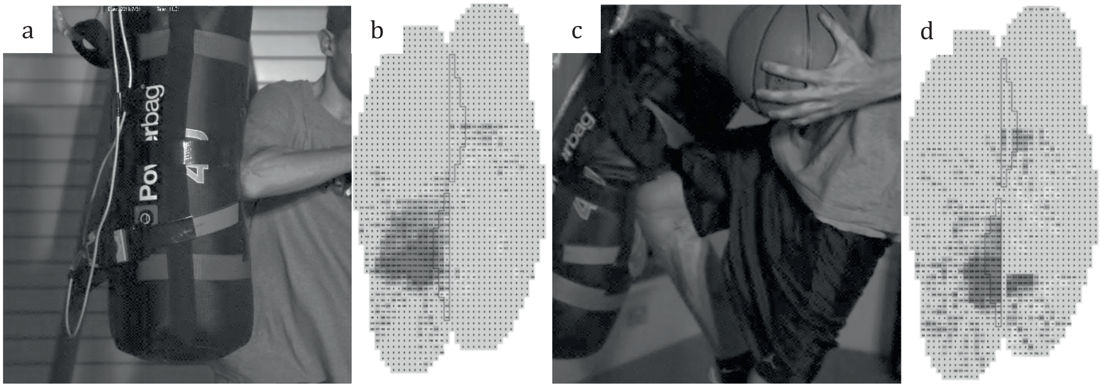

Fig. 3. Example (a) elbow impact and (b) corresponding pressure data; (c) knee impact and (d) corresponding pressure data.

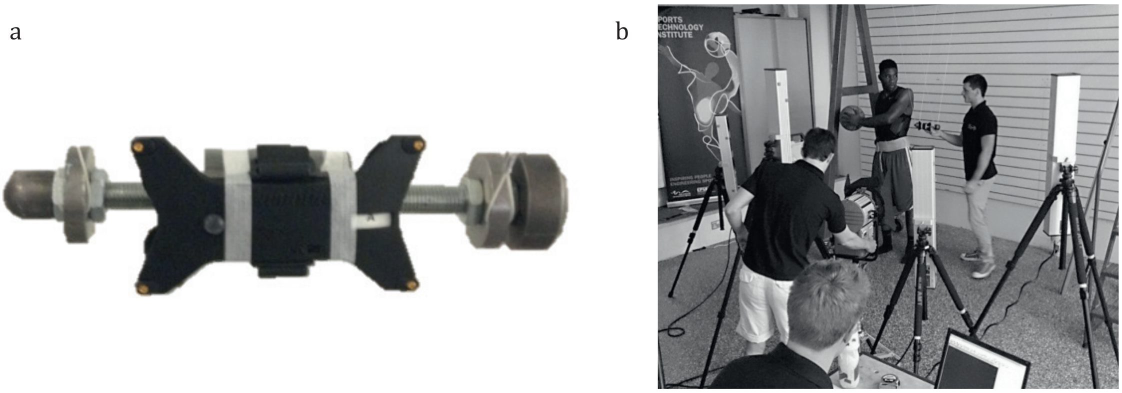

Fig. 4. (a) Artificial impactor used in second and third testing phases; (b) third testing phase experimental set-up

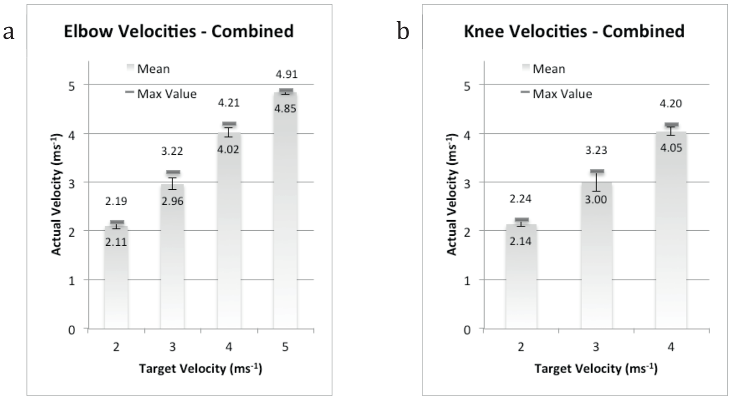

Fig. 5. Combined velocities for (a) "elbow" impacts and (b) knee impacts

In order to replicate the pressure measurements obtained during the human-on-bag phase, an impactor with radii of curvature of 12.5 mm (Wadia et al., 2007) and 37.5 mm (Osterhoff et al., 2011), as shown in Fig. 4a, was developed. The impactor was suspended using light inextensible strings and released from a number of drop heights necessary to achieve 1-5 m/s impact velocity with 1 m/s resolution. The nominal contact duration observed with the impactor was significantly shorter than that observed during the human-on-bag impact (circa 50 vs. 200 ms) owing to the rigid nature of the impactor vs. the compliant nature of the human body. For the same reason, the required force levels were achieved with relatively low mass: 2 kg for the elbow impact generated a nett force of 318 (7) N at 5 m/s impact velocity and 2.8 kg for the knee impact generated a force of 1044 (74) N at 4 m/s.

During the impactor-on-human testing, as shown in Fig. 4b, impact velocities of 2-5 m/s with a 1 m/s resolution were arranged. Velocity data achieved are shown in Fig. 5. A single pressure sensor (rather than a pair) per location was used in this phase due to the increased relative control of the impact location. Example impacts and corresponding pressure data are shown in Fig. 6.

4. Discussion & Conclusions

This study provides a good understanding of appropriate masses and velocities required to simulate gameplay basketball impacts. The pressures determined in the impactor-on-human trials were in general lower than those determined in impactor-on-bag impacts which could be explained by the reduced force transferred through the

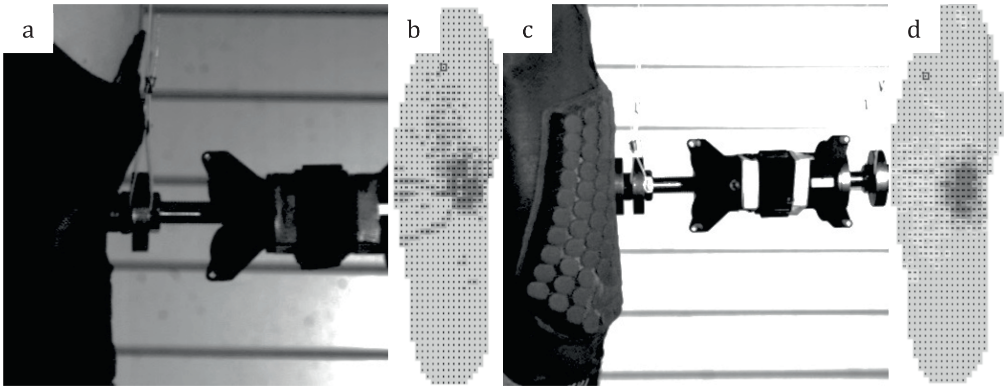

Fig. 6. Example impactor (a) “elbow” impact and (b) corresponding pressure data; (c) “knee” impact and (d) corresponding pressure data.

personal protective equipment. This is the first time such a study has been undertaken and this represents an important step towards understanding human response to impacts in sport, specifically in basketball. There are, however, several areas in which improvements could be made.

Firstly, the pressure measurement system used is being deployed outside of its typical application envelope and results must, therefore, be interpreted with caution. A more flexible, less invasive pressure measurement system with a higher sensitivity range, accurate dynamic calibration and minimal sensitivity drift would represent an ideal solution. Secondly, the impactor used could have been made more bio-fidelic to represent the viscoelastic nature of human tissue. Variable stiffness and damping should ideally be incorporated to tune the impactor for the representation of different types of human tissue. The result, of course, would be a prolonged contact duration.

The three phased protocol used in this study provided an important means of facilitating human impact testing within ethical limitations and provided useful human response data. The initial phase of testing investigated human-on-bag impacts and provided velocities, contact times, pressure distributions, peak pressures, and peak forces. The second phase of testing investigated the masses necessary to replicate the human-on-bag impacts in a controlled pendulum impactor system, reduced contact times experienced were accounted for through the lack of viscoelasticity present in the artificial impactor. The final phase of testing investigated the human response when subject to representative artificial impactor strikes and provided pressure distributions, peak pressures, contact times, and peak forces for a padded strike on human tissue.

Acknowledgements

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