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Headform mounting performance in cricket standard testing

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Abstract

The current British Standard for head protectors for cricketers specifies a projectile test to ensure that a helmet can prevent the ball penetrating the peak-grille gap and deformation of the grille onto the face. For practical reasons, it is specified that the headform is mounted onto a grounded frame. This study aims to determine whether this “Fixed” mounting technique influences the response of the headform relative to a theoretically preferable “Free” suspension. A pressurised air cannon was used to project a “BOLA”^{TM} ball at three nominal speeds (22, 25 and 28 m/s) and at three target impact locations (136 (Top), 108 (Middle) and 80 (Bottom) mm from the base). High speed video was used to identify the contact duration and accelerometer data were used to assess the peak resultant headform acceleration and velocity during this period.

Generally, good agreement between the two scenarios was found in regard to peak resultant headform acceleration, particularly at the 25 and 28 m/s impact speeds. In terms of headform velocity, the two scenarios showed greater variation when the full contact duration was considered, with root mean square deviations ranging from 1.77 – 5.6 in all testing conditions. However, some portions of the impact were considerably more consistent than others. These initial results indicate that the result of the penetration test, as specified in BS 7928:2013, would be independent of the suspension technique particularly given the convergence of results at the specified standard velocity (28 m/s). Future work should look to identify the loading and unloading phases of an impact, and use this to compare headform response. Thus allowing a more in-depth investigation of headform mounting performance and provide more clarity on the use of the Fixed technique in cricket standard tests.

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Keywords: headform; mounting; standard test; impact; projectile impact; cricket helmet

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1. Introduction

Head protection is commonly available in many sports. A participant’s use of a helmet may be mandated in the rules of a competition, for example in Formula 1^{TM} motor racing [1] and snowboarding [2]. In some sports helmet use may be permitted in the rules, but ultimately be a personal decision aimed at reducing the risk of injury. Until recently, this was the case in cricket [3], however the England and Wales Cricket Board (ECB) have now mandated helmet use in professional cricket from the 2016 season. In extreme cases, the function of a helmet is to prevent death or life changing injury, although in many cases, the role of a helmet is to protect or reassure against more minor injury, disfigurement or discomfort.

Walker et al. [4] reported that, over a 5 year period in New Zealand, 21% of all injuries resulting in the hospitalisation of professional and recreational cricketers were sustained to the head. In elite level cricket, the speed of the ball can exceed 85 mph when bowled or thrown, or higher still when hit by the bat. Although lower speeds are more common at recreational levels of the game, direct contact between the ball and the head, or contact as a result of helmet deformation can still cause injury such as concussions, eye injuries, facial fractures, lacerations [5] or even death [6, 7].

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In order to be sold in Europe, protective helmets must satisfy current standards tests and therefore adhere to certain quality controls [8]. These tests must provide an appropriate performance benchmark without being overly costly to implement and thereby avoid excessive cost being passed to the consumer. For this reason, many standards tests utilize an energy equivalent collision, as proposed by Johnson [9], where a high mass low velocity impact is used to simulate a real life collision. Using this technique, a pass fail criteria can be set and implemented with relative ease. These types of test have however been shown to be dissimilar to the case of a real ball projected at the peak-grille gap of a typical cricket helmet [10]. For this reason, a projectile test was incorporated into the revised British Standard specification [11] for head protectors for cricketers, to ensure that a helmet is capable of preventing facial contact either directly as a ball passes through the peak-grille gap, or as a result of deformation of the faceguard onto the face.

When subjected to a tactile stimulus, human response times have been shown to be no faster than a few milliseconds [12]. Therefore, in such a short duration impact as that seen in a ball-head impact in cricket, the passive stiffness of the neck would likely determine the response of the head, since there would be insufficient time to alter this. The passive stiffness of the human neck has been reported to be no greater than 0.1 Nm/deg in the range of $\pm 20^{o}$ [13], suggesting that, in order to create a more accurate real-life representation of an impact, a freely suspended headform would be more appropriate than a rigid mounting. In various cases where impacts have been broadcast and a player has recoiled or been knocked to the ground, these movements occur after tenths or whole seconds have elapsed, suggesting that recoil is not entirely due to the force imparted by the ball during contact.

During an impact, the responses of the colliding bodies are determined by the masses of the bodies and the forces that are applied. However, if contact duration is sufficiently short, the stress waves induced by the impact may not propagate sufficiently to recruit all of the mass of the larger body before they separate, suggesting that the method by which the greater body is suspended is unlikely to be significant. If, as is the practical case, both bodies have a finite stiffness, some deformation will occur and contact duration will be dependent on a more complex series of parameters. When contact cannot be assumed to be negligibly short in duration, the method by which the greater body is suspended is likely to have a more significant effect on the collision.

The British Standard for head protectors for cricketers specifies the use of a rigidly mounted standard headform during projectile testing. The aim of this study was to consider this practical case and determine whether a rigidly mounted headform, preferred for reasons of practicality, offers sufficient similarity to a freely suspended headform (recommended to best represent the theoretical case) to justify its inclusion within testing protocols. This was investigated through high-speed video based observations of the behavior of both colliding objects and accelerometer measurements representing the motion of the headform.

2. Methodology

A bespoke experimental arrangement allowed for the suspension of an instrumented British Standard magnesium headform (size 575) [14] (mass 4.7 kg) in Free and Fixed scenarios. In reality, neither of the scenarios is truly free nor fixed but lies somewhere between these two extremes. In the Free scenario the headform was inverted and suspended with bungee cords (10 mm diameter) attached to the base. In the fixed scenario the headform was mounted via an anti-vibration type bushing onto a grounded frame. The bushing includes a silicon rubber element (PT Flex 60, Polytek, Pennsylvania) which enabled constraint of the headform, while allowing some rotation about the pivot (105 mm from the base of the headform) upon disturbance from rest. The stiffness values of the two suspension techniques were determined by applying a force to the headform in line with the basic plane and measuring the resulting static displacement. The stiffnesses were found to be 1.8 N/mm for the Free scenario and 185 N/degree (equivalent of 49.8 N/mm at the basic plane) for the Fixed.

Throughout all tests the same type of “BOLA”$^{\text{TM}}$ cricket training ball (mass 150 g, diameter 71 mm), as specified in the BS 7928:2013 [11], was used. A pressurised air cannon was used to project the ball toward the headform at three impact speeds, nominally 28, 25 and 22 m/s. The experimental arrangement allowed for the vertical position of the headform to be adjusted and therefore allowed for impacts to occur at three impact locations, nominally 136 (“Top”), 108 (“Middle”) and 80 (“Bottom”) mm from the base of the headform. The Top and Middle impact locations are aligned with the headform Reference and Basic planes respectively, and the Bottom location is the same distance from the Middle that the Top is, but in the opposite direction. In the British Standard, a helmet is fitted onto the headform thereby adding compliant materials which would influence the impact mechanics. However, as any differences between the mounting techniques would be most pronounced with bare headfrom impacts, no helmets were used throughout the testing.

A PCB 356B21 triaxial accelerometer was fitted inside the headform using a mount. The accelerometer was secured on the central axis, 127 mm from the base of the headform and was orientated relative to the headform such that the x, y and z axes corresponded to superior-inferior, medio-lateral and anterior-posterior movements respectively. Once conditioned the accelerometer signals were recorded using a LeCroy WaveJet 324 digital oscilloscope with a sample frequency of 50MHz. The accelerometer sensitivities were determined in advance, as 1.18, 1.22 and 1.17 mV/m/s^2 in the x, y and z directions respectively.

Three Arri Pocket par 400 lights were used to illuminate the testing area. A Photron FastCam SA1 mono high-speed camera, operating at 50 kHz (448 x 224 spatial resolution) was positioned lateral and perpendicular to the plane of movement, 635 mm from the headform. This allowed for a view of a portion of the headform and around 140 mm of the ball trajectory prior to and post impact.

Prior to each trial the headform was repositioned in order to achieve the required impact location. Although this was always necessary in the Free scenario, it was not required in the Fixed scenario, highlighting the practical advantage of the Fixed arrangement. As there was some variation in the trajectory of the ball out of the cannon, a second high-speed camera (Photron FastCAm Ultima APX mono, operating at 10 kHz) was positioned above the impact location in order to ensure that only impacts occurring within 5 mm of the intended target location were retained. Variation in ball speed was also observed. A pair of timing light gates, separated by a distance of 200 mm, were used to measure the actual ball speed; thus allowing only trials that fell within ±1 m/s of the target impact velocities to be retained. The final timing light gate was used to trigger the high-speed video cameras and accelerometer synchronously.

A MATLAB script was written in order to enable efficient processing of high-speed video data. The script employed edge detection techniques to identify the headform and the ball in each video frame and the frames in which initial contact and final contact occurred were identified. Conversion from pixels to mm was performed by using the ball diameter – measured to be 71 mm using a Vernier caliper.

Accelerometer data were processed in Microsoft Excel, with the sensitivities applied to convert from V to SI units. Analyses of the data sampled at 50 MHz revealed that no meaningful signal artefacts would be lost by subsampling by a factor of 100. Since the accelerometer and high-speed video data were synchronised, the timestamp of the frames identified as initial and final contact were used to interrogate the accelerometer signal during the contact duration. Acceleration in the x, y and z directions were time domain integrated in order to find velocity. Velocity traces were interrogated and average curves during the loading and unloading phases were calculated. In order to account for the uncertainty in the identification of initial and final contact, these calculations were performed at the identified key frames as well as the frames either side of these. This was found to have little effect, with observed differences of less than 1%.

3. Results

3.1. Peak resultant headform acceleration

Table 1 shows the mean and standard deviations of the peak resultant headform accelerations observed in the Free and Fixed scenarios. In both scenarios, the peak resultant acceleration increases with inbound ball speed, as should be expected. Generally there are no distinct differences between the two scenarios, as when standard deviations are considered, there is substantial overlap at the 28 and 25 m/s impact speeds. There is slightly more variation at the 22 m/s impact speed as the Free scenario exhibits slightly greater peak headform acceleration at the Top and Middle impact locations, but a slightly lower value at the Bottom location. Figure 1 shows that the data points are distributed similarly and over a similar range, with relatively good clustering. The data points appear to converge at the 28 m/s impact speed, as there are less pronounced differences here than at the 22 m/s impact speed where some separation appears evident. Figure 1 suggests that in the conditions where standard deviations were high, this was due to a genuine distribution of data points as opposed to individual outliers.

Table 1. Mean and standard deviation values of the average peak resultant headform acceleration.

	Fixed				**Free**			
	Impact Speed (m/s)		**Peak Resultant Acceleration (m/s^{-2})**		**Impact Speed (m/s)**		**Peak Resultant Acceleration (m/s^{-2})**	
Impact Location	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Top	27.9	0.6	4684	435	27.6	0.6	4584	295
	24.2	0.5	3868	423	24.0	0.8	3890	258
	21.3	0.2	2909	97	22.0	0.4	3621	179
Middle	27.1	0.3	4803	171	28.1	0.8	4638	283
	23.6	0.4	3497	515	24.0	0.8	4008	170
	21.3	0.6	2747	269	21.8	0.4	3422	92
Bottom	27.4	0.3	4628	298	28.1	0.6	4833	654
	24.2	0.6	4293	250	24.0	0.7	3782	86
	21.5	0.6	3750	192	21.6	0.5	3316	113

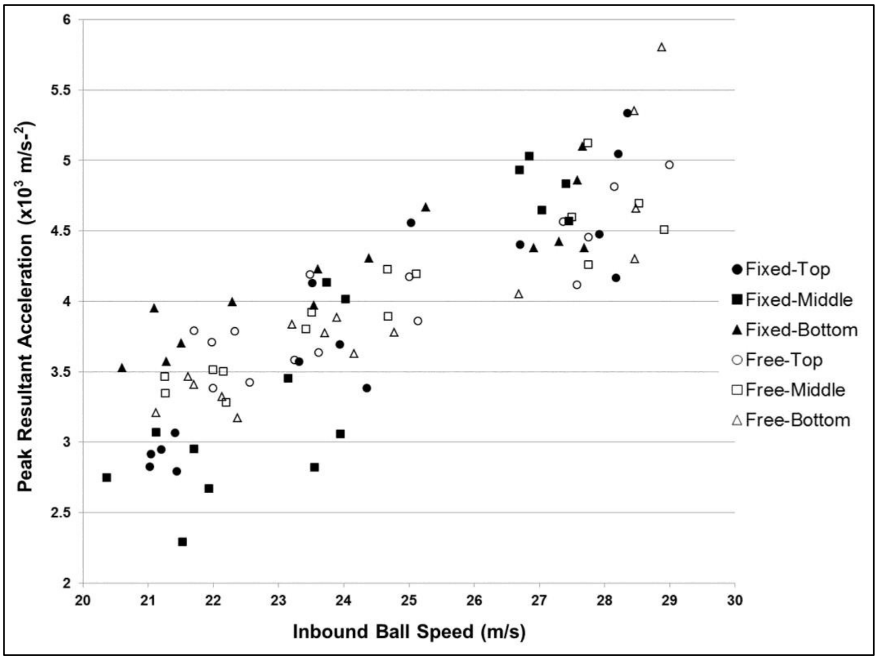

Figure 1. Peak resultant headform acceleration vs Inbound ball speed.

3.2. Change in headform speed

Figure 2 shows the average change in headform speed at the end of the contact duration. As expected, greater inbound ball speed resulted in a greater change in headform speed. Generally the distribution of data points suggests that there is a greater change in headform speed in the Free scenario than in the Fixed, as the solid data points tend to sit below the outlined equivalents. These differneces may be explained by the average headform speed traces.

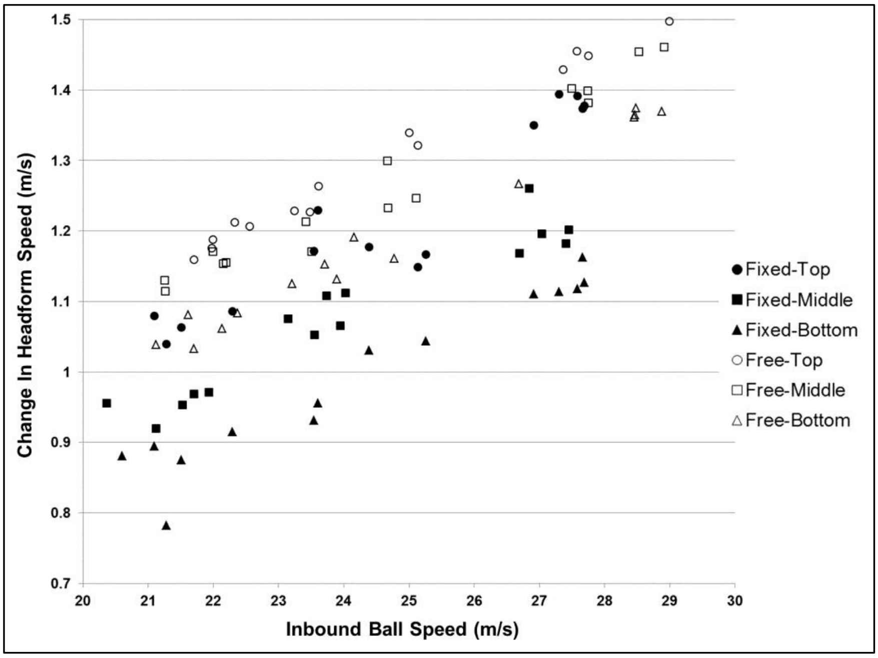

Figure 2. Change in headform speed vs Inbound ball speed.

Average headform speed traces for each impact speed at the Top (a), Middle (b) and Bottom (c) impact locations during the contact duration can be seen in Figure 3. Generally, there is close agreement in terms of gradients and peak headform speed between the Free and Fixed scenarios during the initial period of the contact duration up to peak speed, and the standard deviations of these traces (although not shown here for purposes of clarity) show significant overlap throughout this duration. In the latter portion of the contact duration, clear differences between the Free and Fixed headform can be observed, particularly at the middle and bottom impact locations, where the headform undergoes measurable deceleration in the Fixed scenario when compared to the Free. However, as facial contact would likely result from the initial 'loading' phase of an impact, this should be considered the most important period. In order to quantify the differences between the two suspension scenarios, the root mean square deviation (RMSD) was calculated for each testing condition, where a higher value indicates a greater difference. At the

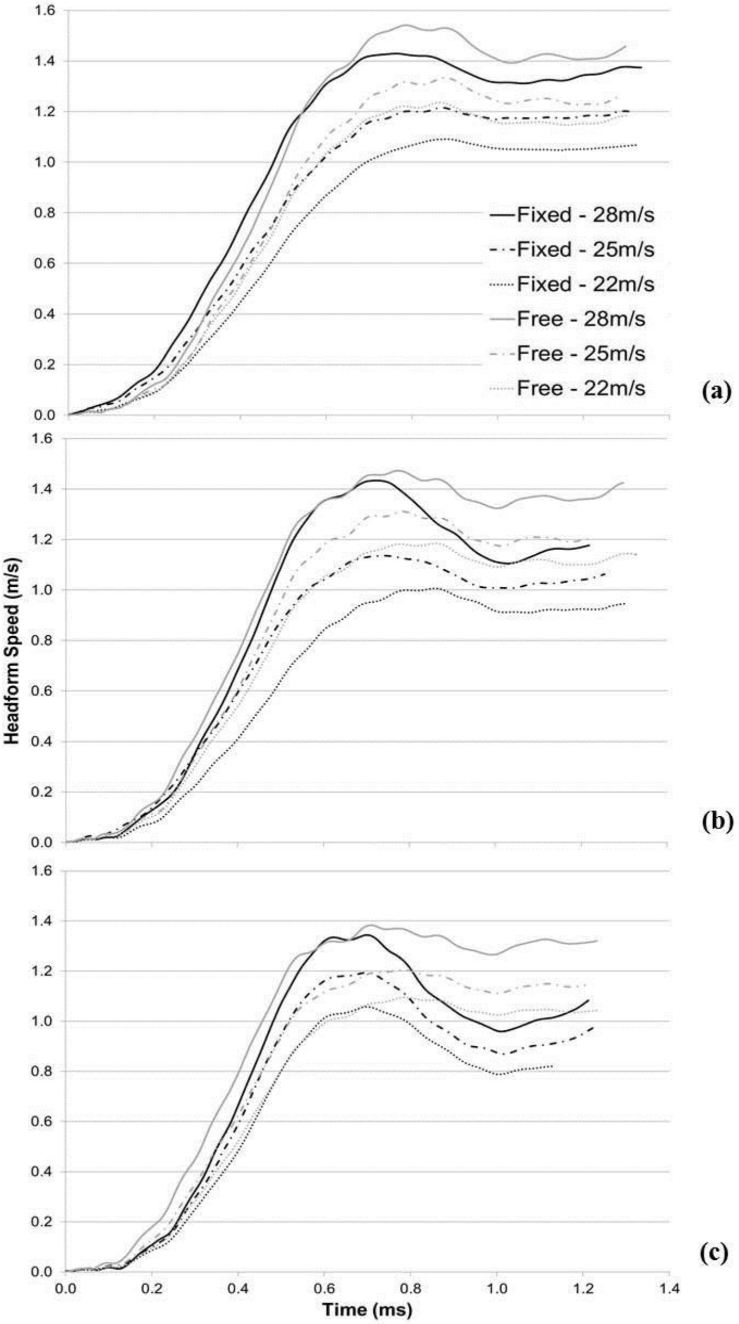

Figure 3: Average headform speed traces vs Time at the Top (a), Middle (b) and Bottom (c) impact locations during the contact duration.

Top, Middle and Bottom impact locations the RMSD was found to vary between 1.77 – 2.96, 2.88 – 3.92 and 3.06 – 5.6 respectively. These values may be higher than expected given that the RMSD was calculated for the entire duration of contact and therefore includes the aforementioned variations arising in the latter part of the impact. Future work should look to investigate the differences between the mounting techniques in both the initial ('loading') and latter ('unloading') portions of the impact.

4. Conclusions

There were found to be few substantial differences between the Free and Fixed scenarios in terms of peak resultant headform acceleration. This is of particular importance as this provides an indication of the peak force applied to the headform during contact. Although some variation was observed between the two scenarios at 22 m/s, with impact speeds of 28 and 25 m/s there were few differences between the two suspension techniques and substantial overlap when standard deviations were considered. In regard to headform speed, there were clear differences between the two scenarios in the latter period of contact, as the Fixed scenario exhibited measurable deceleration of the headform that was not apparent in the Free scenario, especially at impact locations close to the mounting position. It is reasoned however that, should any facial contact occur during the BS 7928:2013 [11] penetration test, this would be directly related to the initial or 'loading' phase. As the restoring force has the greatest influence in the latter stages of the impacts, this may not influence the result of the standard test. Future work should look to quantify the differences in these, and other, parameters during the 'loading' and 'unloading' phases of an impact. This may be done through the assessment of ball deformation, thereby allowing the definition of the loading (the period from initial contact to maximum ball deformation), and unloading (the period from maximum ball deformation to the end of contact) phases. This would allow a clearer understanding of the mechanics of the collision and allow similarities and differences between suspension techniques to be identified with greater certainty.

As the British Standard Specification requires an impact speed of 28 (±3) m/s, the results conducted at these impact speeds should be considered more important. At this impact speed and at 25 m /s the peak resultant headform acceleration was found to be similar between the two arrangements at all impact locations. Due to this, and the apparent similarities between the two scenarios in terms of headform speed, particularly during the initial period of impact, utilizing the Fixed mounting at 25 and 28 m/s impact speeds appears more legitimate.

Overall this initial explorative study appears to, for the first time, show that for the purposes of standard testing, the response of the headform for the penetration test specified in BS 7928:2013 [11] is independent of the suspension technique. Although this suggests that the Free and Fixed suspension arrangements are similar enough to be used interchangeably and therefore that the Fixed arrangement is satisfactory for standard testing, further work should be done to ascertain, with more certainty, if this is the case.

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