What are the most effective risk-reduction strategies in sport concussion?

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ABSTRACT

Aim To critically review the evidence to determine the efficacy and effectiveness of protective equipment, rule changes, neck strength and legislation in reducing sport concussion risk.

Methods Electronic databases, grey literature and bibliographies were used to search the evidence using Medical Subject Headings and text words. Inclusion/exclusion criteria were used to select articles for the clinical equipment studies. The quality of evidence was assessed using epidemiological criteria regarding internal/external validity (eg, strength of design, sample size/power, bias and confounding).

Results No new valid, conclusive evidence was provided to suggest the use of headgear in rugby, or mouth guards in American football, significantly reduced players' risk of concussion. No evidence was provided to suggest an association between neck strength increases and concussion risk reduction. There was evidence in ice hockey to suggest fair-play rules and eliminating body checking among 11-years-olds to 12-years-olds were effective injury prevention strategies. Evidence is lacking on the effects of legislation on concussion prevention. Equipment self-selection bias was a common limitation, as was the lack of measurement and control for potential confounding variables. Lastly, helmets need to be able to protect from impacts resulting in a head change in velocities of up to 10 and 7 m/s in professional American and Australian football, respectively, as well as reduce head resultant linear and angular acceleration to below 50 g and 1500 rad/s^2, respectively, to optimise their effectiveness.

Conclusions A multifactorial approach is needed for concussion prevention. Future well-designed and sport-specific prospective analytical studies of sufficient power are warranted.

INTRODUCTION

Concussion may be caused either by a direct blow to the head or an indirect blow elsewhere to the body that creates an 'impulsive' force that is transmitted to the head.[1] Concussion is presently one of the most prominent medical concerns in contact/collision sports at all ages and levels of competition. Currently, the best treatment for concussion appears to be prevention, but this has been a daunting task for medical professionals, scientists and sport-governing bodies. Specific risk factors are poorly delineated and rarely studied, providing little evidence upon which to base effective preventive strategies. To date, concussion prevention strategies have focused on equipment, rules and rule enforcement, refereeing, coaching techniques, neck strength, respect/behaviour/fair play, education programmes and legislation focused on concussion in youth athletes.[2–10]

The objective of this study was to critically review the published evidence on the role of modifiable intrinsic and extrinsic factors in sport concussion prevention, with a specific focus on equipment (clinical and biomechanical), rules changes, neck strength and legislation. Concussion education as a primary, secondary and tertiary prevention strategy is beyond the scope of this article.

METHODS

Data sources

For equipment, 11 electronic databases were searched using a combination of Medical Subject Headings and text words by means of 'wild cards' and Boolean operators to identify potential clinical studies. The search strategy used was: (1) (mouthguard$ OR (mouth guard$) OR (mouth protect$) OR (gum shield)); (2) (helmet$ OR headgear$ OR (head protect$)); (3) ((face shield$) OR visor$ OR (face protect$)); AND (concussion$ OR (brain injur$) OR (head injur$) OR injur$); AND sport$. Studies were limited to human studies, English language and publications between 2008 and 19 September 2012 to update the evidence summarised in a previous systematic review on this topic.[4] For neck strength, rules and legislation, 10 databases were searched using the key words 'neck strength OR rules OR legislation AND concussion AND sport AND prevention'. PubMed was the primary electronic search engine used to identify human biomechanical studies between 1998 and September 2012 using 'biomechanics AND brain concussion AND sport'. Furthermore, the bibliographies of selected articles and the grey literature (eg, Google Scholar) were used to identify articles not revealed by the above search strategies. The electronic databases and number of potentially relevant citations identified for the clinical equipment studies and neck strength, rules and legislation studies are shown in tables 1 and 2, respectively.

Study selection

Inclusion criteria for the clinically related equipment papers were as follows: (1) original data; (2) cross-sectional, prospective case series, case control, retrospective and prospective cohort, quasi-experimental or experimental study designs; (3) outcome included a measure of concussion sustained in sport; (4) studied concussions associated with mouth guard, helmet, headgear or facial protection use; (5) exposure included some measurement of mouth guard, helmet, headgear or facial protection use; (6) male or female individuals;

Table 1 Electronic search strategy for clinical studies on protective equipment use and concussion, with number of identified citations

Electronic database	Search strategy	Number of helmet/headgear citations	Number of mouth guard citations	Number of face shield citations
Ovid MEDLINE (2008–19 September 2012)	1 OR 2 OR 3	107	95	8
Ovid Healthstar (2008–19 September 2012)	1 OR 2 OR 3	99	90	8
SportDiscuss (2008–September 2012)	1 OR 2 OR 3	55	80	3
EMBASE (2008–19 September 2012)	1 OR 2 OR 3	198	114	20
PubMed (2008–19 September 2012)	1 OR 2 OR 3	60	10	4
CINAHL (2008–September 2012)	1 OR 2 OR 3	2	23	1
Ovid OLDMEDLINE (2008–19 September 2012)	1 OR 2 OR 3	0	0	0
Cochrane Database of Systematic Reviews (2008–19 September 2012)	1 OR 2 OR 3	1	0	0
Database of Abstracts of Reviews of Effects (2008–19 September 2012)	1 OR 2 OR 3	7	5	1
Cochrane Central Register of Controlled Trials (2008–19 September 2012)	1 OR 2 OR 3	5	4	0
AMED—Allied and Complementary Medicine (2008–19 September 2012)	1 OR 2 OR 3	3	0	1

(7) all ages; (8) all levels of competition; (9) all sports and (10) English language. Exclusion criteria included: (1) review articles, case reports, commentaries or letters to the editor; (2) no measure of mouth guard, helmet, headgear, or face shield exposure and (3) studies exclusively examining head injuries other than concussion. One reviewer each for the clinical equipment studies, biomechanical studies, rules, neck strength and legislation screened the titles and abstracts. If insufficient information was available (eg, no abstract), the full papers were reviewed. For studies pertaining to rules, neck strength and legislation, no a priori inclusion/exclusion criteria were used owing to the paucity of articles identified from the search strategy.

Data extraction, validity assessment and study characteristics

The following study characteristics were used to assess the quality of evidence for the clinical equipment studies: study design; study population; sample size; exposure and outcome measures; type of mouth guard, helmet, headgear or facial protection studied and results. The quality of evidence was assessed based on epidemiological criteria regarding internal and external validity (ie, strength of design, sample size/power, elimination or control of factors such as selection bias, misclassification bias, confounding and effect modification). A narrative approach was used to describe and synthesise the results of the clinical studies owing to the heterogeneity of study designs, variety of prevention strategies used and diversity of sports assessed.

RESULTS

Equipment—clinical studies

Inclusion and exclusion criteria were applied resulting in the retrieval of only three articles (one mouth guard and two headgears) since a previous systematic review of the literature.[4] No new clinical studies were identified for facial protection. Table 3 highlights the characteristics of the studies selected for review.

Singh *et al*[11] conducted a longitudinal cross-sectional study of mouth guards utilising 28 American football players (mean age 17.3 years±1.9 at study onset) over three seasons. The mean self-reported incidence of concussion was 2.1±1.4 concussions prior to the use of a customised mandibular orthotic (CMO) and 0.11±0.3 concussions after the use of the CMO (OR: 38.3, 95% CI 8.2 to 178.6), $p<0.05$).[11] Specific to helmet/headgear use, Hollis *et al*[12] conducted a cross-sectional study to estimate the incidence of concussion and identify risk factors in Australian non-professional male rugby players (N=3207) over one or more seasons. Players who self-reported always-wearing protective headgear during games were at a reduced risk of sustaining a concussion (incidence rate ratio (IRR): 0.57; 95% CI

Table 2 Number of citations identified from the electronic databases for studies pertaining to the role of neck strength, rules and legislation in sport concussion prevention

Electronic database	Number of neck strength citations	Number of rules citations	Number of legislation citations
Ovid MEDLINE (1946–September 2012)	6201	337	428
Ovid Healthstar (1966–November 2012)	0	3	0
SportDiscuss (1998–2012)	0	0	0
EMBASE (1980–2012 week 50)	1	22	2
PubMed (1960–September 2012)	3	17	9
CINAHL (1998–September 2012)	0	3	0
Ovid OLDMEDLINE (1946–1965)	0	0	0
Cochrane Database of Systematic Reviews (2005–November 2012)	0	0	0
Database of Abstracts of Reviews of Effects (4th Quarter 2012)	0	0	0
AMED—Allied and Complementary Medicine (1985–December 2012)	0	2	0

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Table 3 Clinical study characteristics pertaining to concussion and protective equipment use (1998–September 2012)

Study	Study design	Duration (seasons)	Sport	Study population	Exposure measures	Outcome measures	Results
Singh *et al*[11]	XS	3	American football	28 Males (mean age: 17.3±1.9 years at study onset)	Customised mandibular orthotic (CMO) (preuse- and postuse)	Concussion	Mean self-reported incidence prior to CMO use: 2.1±1.4 Mean self-reported incidence after CMO use: 0.11±0.3 OR 38.33 (95% CI 8.2 to 178.6)
Hollis *et al*[12]	XS	1 or more	Australian non-professional rugby	3207 males	Headgear use	Concussion	Players reporting always wearing headgear during games were at a reduced risk of sustaining a concussion (IRR, 0.57; 95% CI 0.40 to 0.82)
McIntosh *et al*[13]	CRCT	2	Rugby Union Football	Males from U13, U15, U18 and U20 (ages 12-21 years) (n=3686)	No Headgear use, Standard Headgear use, Modified Headgear use	Concussion: Game Injury or Time-Loss (n=199)	No significant difference in concussion rates between the three arms of the study (p>0.05)

CRCT, cluster-randomised controlled trial; IRR, incidence rate ratio; XS, cross-sectional.

0.40 to 0.82). The second study was a cluster-randomised controlled trial (RCT) of headgear use in male youth rugby union over two seasons.[13] Three study arms were used: no headgear was used, standard headgear was used (10 mm thickness) and modified headgear was used (16 mm thickness and denser protective foam than the standard headgear). Trained paid data collectors recorded headgear compliance and exposure at each game and ascertained the outcome of interest in conjunction with team medical staff. Intention-to-treat analysis revealed no significant difference in concussion rates between the three groups ($p>0.05$) as well as no increase in overall injury rates with the use of padded headgear ($p>0.05$).

Limitations

The studies by Singh *et al*[11] and Hollis *et al*[12] had several limitations which threaten the validity of the results (ie, non-randomised, no control group, equipment self-selection bias, self-reported exposure and outcome (a source of misclassification bias), lack of sample-size calculations and a failure to control for potential confounding factors). Limitations of the study by McIntosh *et al*[13] included poor compliance with headgear use as well as lack of control for potential confounding variables such as previous history of concussion, player position and behavioural factors/attitude.

Equipment—biomechanical studies

Observational, laboratory and computer simulation studies have been conducted to understand the nature of game events that cause concussion, measure loads applied to the head, load responses of the head and estimate patterns of brain loading associated with injury. Table 4 highlights a comparison of linear and angular head acceleration maxima for concussive and non-concussive head impacts in American football.

Impact characteristics, brain injury mechanisms and tolerance criteria

Head impacts have been characterised by: injury outcome, head location, striking object, velocity, energy, impact force, head linear acceleration and head angular acceleration and velocity. Knowledge of these parameters provides the basis for performance specifications for protective equipment such as helmets.[32–34] In professional American football the average head-to-head impact speed in concussive impacts were 9.3 m/s with an average change in velocity of the concussed head of 7.2 m/s compared with 5.8 m/s for the non-helmet wearing footballers in Australia.[29 31 35] The mean peak head linear and angular accelerations for concussed players in these two cohorts were similar, 98 g and 6432 rad/s^2 in American football compared to 103 g and 8022 rad/s^2 in Australian football.[29 31 35]

Critical to the design of effective equipment are valid human tolerance criteria or limits. For concussion, a range of limits has been proposed. Zhang *et al*[36] proposed tolerance levels for concussion of linear head acceleration <85 g, angular acceleration < 6000 rad/s^2 and a HIC_{15} <240. Rowson *et al*[21] observed a 50% likelihood of concussion associated with an angular acceleration of 6383 rad/s^2 and angular velocity of 28.3 rad/s. McIntosh observed a 50% likelihood of concussion associated with a peak linear acceleration of 76 g,[33] and 98.9 g represented a 75% probability of concussion according to the analysis by Pellman *et al*.[37] There remains debate about tolerance levels, and more complex criteria have been proposed such as the weighted principal component score which incorporates linear and angular head acceleration variables plus impact location, while others have considered cumulative load.[17 18 38–40]

Neck strength

Weak neck musculature has been postulated as a concussion risk factor. In theory, increasing cervical muscle strength may reduce head linear and rotational kinematics during impact and resultant brain loading. Four studies were identified for review specific to this topic area. Although the studies demonstrated: (1) significant neck strength increases after an 8-week resistance training programme,[41] (2) significant differences in strength between specific cervical muscle groups[42] and (3) significant strength differences between sexes,[43 44] the authors did not assess whether there was an association between differences in neck strength and/or head accelerations and a reduction in concussion incidence on the playing field. Overall limitations of the selected studies included measuring cervical strength isometrically rather than dynamically, failure to measure muscle activation associated with head impact biomechanics, and failure to control for level of anticipation. Furthermore, there was a lack of control for previous concussion history and cervical spine injury.

Rules

Rule changes have been postulated as a risk-reduction strategy for sport concussion,[45 46] but an overall paucity of studies were identified that specifically assessed the role of rule changes on

Table 4 Comparison of linear and angular head acceleration maxima in concussive and non-injury head impacts in American football

Study	Mean peak resultant linear head acceleration (g)		Mean peak resultant angular head acceleration (rad/s^2)		Number of cases		Sport	Level	Method	No. participants (if cohort study)
	No injury	Concussion	No injury	Concussion	No injury	Concussion				
Brolinson *et al* (2006)[14]	20.1	103.3	NM/NR	NM/NR	11601	3	American football	Collegiate	Instrumented helmets	
Crisco *et al* (2011)[15]	20.5	Nil	1400	Nil	286636	0	American football	Collegiate	Instrumented helmets	314 Players, 3 seasons
Duma *et al* (2005)[16]	32	81	NM/NR	NM/NR	3311	1	American football	Collegiate	Instrumented helmets	
Funk *et al* (2012)[17]	Range 10–250	145	NM/NR	NM/NR	37124	4	American football	Collegiate	Instrumented helmets	98 Players in total over a total of 5 seasons
Guskiewicz *et al* (2007)[18]	–	102.8	–	5312	0	13	American football	Collegiate	Instrumented helmets	
Mihalik *et al* (2007)[19]	22.25	NM/NR	NM/NR	NM/NR	57024	NM/NR	American football	Collegiate	Instrumented helmets	72 In total over a total of 2 seasons
Rowson *et al* (2009)[20]	median=17.5	Nil	median=1017	Nil	1712	0	American football	Collegiate	Instrumented helmets	10 Players, 1 season
Rowson *et al* (2012)[21]	–	103	1230	5022	300977	57	American football	Collegiate	Instrumented helmets	
Breedlove *et al* (2012)[22]	27.5 (COI−/FOI −)	28.5 (COI+/FOI+), 27.7 (COI−/FOI+)	NM/NR	NM/NR	1463 (COI −/FOI−)	1551 (COI+/FOI+), 1855 (COI−/FOI+)	American football	High school	Instrumented helmets	21 season 1, 25 Season 2
Broglio *et al* (2009)[23]	25	Nil	1468.6 to 1669.8	Nil	19224	0	American football	High school	Instrumented helmets	35
Broglio *et al* (2010)[24]	25.1	105	1627	7229.5	54247	13	American football	High school	Instrumented helmets	78
Broglio *et al* (2011)[25] and Broglio *et al.* (2011b)[26]	24 to 27	93.6	1500–1790	1753.9	101974	20	American football	High school	Instrumented helmets	95 over 4 seasons
Naunheim *et al* (2000)[27]	29.2	NM/NR	NM/NR	NM/NR	132	0	American football	High school	Instrumented helmets	
	35	NM/NR	NM/NR	NM/NR	128	0	Hockey	High school	Instrumented helmets	
	54.7	NM/NR	NM/NR	NM/NR	23	0	Soccer	High school	Instrumented helmets	
McIntosh *et al* (2009)[28] and Frechede and McIntosh (2009)[29]	59	103.4	5541	8020	13	27	Australian football	Professional	Rigid body simulations	
Newman *et al* (2005)[30]/ Pellman *et al* (2003)[31]	54.3	97.9	4159	6664	33	25	American football	Professional	ATD reconstructions	

+, presence of impairment; −, absence of impairment; COI, clinically observed impairment; FOI, functionally observed impairment; NM/NR, not measured or not reported.

sport concussion risk. Four studies specific to this topic area were selected for review in ice hockey and two in rugby.

In ice hockey, a state-wide analysis of a Hockey Education Program (HEP) designed to decrease violence in youth hockey while promoting sportsmanship and skill development revealed a 30% reduction in potentially dangerous infractions such as checking from behind and hits to the head after the first 4 years of implementation.[7] In addition, Roberts *et al*[10] showed that fair-play rules (ie, team tournament points added for staying under a pre-established limit of penalties per game) compared with regular rules reduced concussions, facial lacerations and time-loss injuries combined, among high-school hockey players. Macpherson *et al*[46] revealed that players aged 10–13 years were more likely to experience a concussion (OR: 1.53; 95% CI 0.93 to 2.52) where body checking was permitted. Furthermore, Emery *et al* revealed that the IRR of game-related concussions for 11-year-old to 12-year-old ice hockey players competing in a body checking league (Alberta, Canada) versus league not permitting body checking (Quebec, Canada) was 3.88 (95% CI 1.91 to 7.89) and 3.61 (95% CI 1.16 to 11.23) for concussions resulting in time loss >10 days.[47]

In rugby, Gabbett investigated the incidence of injury in Rugby League players before and after the introduction of the limited interchange rule.[48] They found a 30% reduction in injury risk (relative risk (RR): 0.70, 95% CI 0.65 to 0.75, $p<0.05$) during matches played under the limited interchange rule versus unlimited interchange rule. The incidence rates for concussion and open head wounds combined fell from 5.1 injuries per 1000 player-hours to 3.0 per 1000 player-hours. Gianotti and Hume[49] assessed Rugby Union's 2003 concussion management education programme (RugbySmart). From 2003 to 2005, new rugby concussion/brain injury moderate to serious Accident Compensation Commission insurance claims reduced by 10.7% demonstrating the benefits of the sideline concussion checklist and management tool.

Legislation

Despite the interest generated through media exposure and public education programmes,[50] there appears to remain widespread misconceptions about the diagnosis and management of concussion,[51–53] as well as knowledge gaps among athletes, parents and coaches.[54] While gains in concussion knowledge and retention of that knowledge can be demonstrated with educational campaigns,[55] education alone often results in the implementation of a concussion programme that is successful only as long as a certain coach or administrator remains with a team or school. Also, even in the best of circumstances, attempts at initiating such education programmes can be inconsistent and slow.[56] A legislative process has been implemented in the USA to standardise the approach to sport concussions in youth athletes.[57] Patterned on what has been termed the 'Lystedt Law' from Washington State,[58] USA youth concussion legislation includes provisions for: (1) education of athletes, parents and/or guardians and coaches; (2) removal from play or practice at the time of a suspected or confirmed concussion and (3) return to practice or play only with written medical clearance from a licensed healthcare provider trained in the evaluation and management of concussion.[54–57] A survey study of Washington State adults 1 year after the passage of the Lystedt Law revealed that 85% of the study population was aware of the Lystedt Law and over 90% had a good understanding regarding the definition, diagnosis and potential severity of a concussion.[59] At this time, there appears to have been no similar laws to the Lystedt law or any legislation dealing specifically with the regulation of the management of youth sport concussions in other countries.

DISCUSSION

Factors that potentially make an athlete more or less susceptible to injury include a complex interaction between intrinsic and extrinsic risk factors, some of which are modifiable and some are not.[60–64] It is essential to identify and understand the relationships between such risk factors in the quest to design, study and implement valid effective prevention strategies. It is also important to be aware of the dynamic nature of risk that may change over time for the concussed athlete.[64] Little new evidence was found for successful interventions to reduce concussion.

No new valid, conclusive evidence was provided in this review to suggest that current standard headgear use in rugby reduces athletes' risk of concussion.[13] New evidence suggesting that custom-fitted mouth guards protect players from concussions in American football was limited.[11] Current evidence supports the use of helmets in reducing head/brain injury risk among bicyclists, and head injury risk among skiers and snowboarders.[4] The effect of helmet/headgear use on concussion risk is still inconclusive in rugby, football (soccer), ice hockey, American football and rodeo,[4] although the use of helmets in ice hockey and American football have been shown to play an important role in the prevention of skull fracture and severe traumatic brain injury.[65 66] There is no strong evidence of mouth guard use (all sports) or face shield use (ice hockey) in reducing concussion risk.[4] At the same time, there is no evidence to suggest an increased risk of injury with mouth guard or face shield use, and there is evidence to support their use for reducing dental, ocular and facial injuries.[67–73] Furthermore, there was some evidence provided to suggest that full facial protection in ice hockey may reduce postconcussion time loss, which may be considered a marker of concussion severity.[74]

No evidence was provided to suggest an association between neck strength and concussion risk reduction on the playing field. Evidence was provided to suggest that eliminating body checking from Pee Wee ice hockey (ages 11–12 years) is an effective concussion prevention strategy,[47] and that a compulsory annual awareness programme for coaches and referees (RugbySmart) reduces concussion/brain injury-related personal injury claims and associated costs in rugby union.[49] Several other rule/policy/behaviour change strategies have been introduced as concussion prevention strategies by sport associations/leagues, but require further study and scientific validation to determine their effectiveness.

Evidence is lacking on the effects of legislation on primary, secondary or tertiary concussion prevention.[59] The preliminary studies of the efficacy of youth concussion laws in the USA will require expansion and replication in other states with such laws. The validation of such laws in ensuring better management of youth concussions might lead to consideration of similar laws in other jurisdictions. It is important that any such laws, if passed, must be open to ongoing review and amendment as new scientific knowledge about sport concussions is discovered and the best and most effective ways to implement such laws are learnt.[54–56]

From a biomechanical perspective, the most effective method to prevent concussion is to minimise the likelihood and/or severity of a head impact. Based on the biomechanical data presented in this review, helmets need to be able to protect from impacts resulting in a head change in velocity of up to 10 m/s in professional American football, and up to 7 m/s in professional Australian football. It also appears that helmets must be capable of reducing the head's resultant linear acceleration to below

50 g and angular acceleration components to below 1500 rad/s^2 to optimise their effectiveness. While the biomechanical evidence forms an important foundation for future research, there was no direct evidence of preventing concussion.

Lastly, sport-governing bodies need to carefully consider potential injury ‘trade-offs’ associated with the implementation of injury-prevention strategies, because every change may have certain advantages and disadvantages. That is, by reducing one risk or danger, additional risks may be created.[75] Evidence provided by sport scientists/epidemiologists are crucial for making rational policy and safety decisions, but the paucity of valid, conclusive research on concussion prevention makes it difficult to base any such decisions.

FUTURE RESEARCH

The integration of basic science, biomechanical and epidemiological research is important in the pursuit of developing effective equipment-related concussion prevention strategies. Evidence for risk factors cannot always be derived through randomised controlled trial designs, primarily owing to ethical considerations (eg, mandated helmet use in ice hockey and American football). An observational design allows researchers to prospectively observe associations between an exposure of interest (eg, equipment use versus non-use) and concussion in a natural ‘experimental’ setting. However, the research is complex, challenging methodologically, resource intensive and expensive.

Future well-designed and sport-specific prospective analytical studies of sufficient power are warranted for mouth guards, headgear/helmets, facial protection and neck strength. The lack of scientific data supporting specific rule changes should also be addressed with future studies undertaken to not only assess new rule changes or legislation, but also alteration or reinforcement to existing rules. The following design characteristics should be taken into consideration for future concussion prevention studies: (1) natural experimental sport setting, (2) prospective injury reporting, (3) specific target populations, (4) sufficient sample size/power, (5) strict operational definition of concussion and well-defined markers of concussion severity, (6) qualified personnel assessing and reporting injury, (7) validated system of injury surveillance, (8) direct measurement of individual athlete-participation (exposure) and potential risk factor exposure, (9) specifying the exact properties of the equipment tested, (10) accurate recording of mechanism of injury (eg, video analysis), (11) standardised reporting of injury rates so that they are comparable between studies and sports and (12) multivariate analyses adjusting for covariates and controlling for the effects of clustering by team and/or individual.

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Competing interests See the supplementary online data for competing interests (http://dx.doi.org/10.1136/bjsports-2013-092216).

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