Sports Engineering (2023) 26:6
https://doi.org/10.1007/s12283-022-00397-y

TECHNICAL NOTE

Repeatability of a bending stiffness test for snowboarding wrist protectors

G. Leslie[1,2] · K. Winwood[1] · W. Wang[2] · N. Hamilton[3] · T. Allen[2]

Accepted: 22 December 2022 / Published online: 16 January 2023

Abstract

Snowboarding wrist protectors are typically designed to limit impact forces and prevent wrist hyperextension. The standard for snowboarding wrist protectors (ISO 20320:2020) includes a test for measuring their bending stiffness, when fitted to a wrist surrogate. This test serves as a simple means of assessing the ability of wrist protectors to prevent wrist hyperextension. Wrist protector bending stiffness measurements have been shown to be influenced by surrogate design, protector strapping condition, and surrogate surface compliance. Currently, there is a lack of knowledge on the repeatability of bending stiffness measurements, as previous studies have conducted tests during one session. This study investigated the repeatability of a bending stiffness test, by testing two snowboarding wrist protectors (short and long) on two wrist surrogates (compliant and stiff), under three protector strapping conditions (loose, moderate, tight), across three repeated test sessions. Test session had a significant effect ($p < 0.05$) on torque values, with a large effect size ($\eta_p^2 > 0.14$), indicating the test had limited repeatability between test sessions. Despite this limited repeatability, torque values increased with both wrist angle and strap tightness, as reported before, indicating consistent trends in results. The outer surface compliance of the surrogate did not significantly affect the protector's sensitivity to test session nor strapping condition.

1 Introduction

Wrist injuries are common amongst snowboarders, particularly distal radius fractures [1–4]. Such injuries are typically caused by a compressive load applied to a hyperextended wrist during a fall. Snowboarding wrist protectors are designed to prevent injury by limiting impact forces and preventing wrist hyperextension. The first standard for snowboarding wrist protectors was published in 2020 as ISO 20320:2020 [5]. As such, work predating 2020 that characterised snowboarding wrist protectors [6–8] often used, or adapted, test methods from EN 14120:2003 [9], which is specifically for roller sports wrist protectors.

EN 14120:2003 specifies a bending stiffness test for roller sports wrist protectors,[1] as a means of assessing their ability to stiffen the wrist joint and preventing it from hyperextending during a fall on an outstretched hand. A white paper, published in 2013, calling for a standard for snowboarding wrist protectors [1] reviewed this bending stiffness test from EN 14120:2003. Following the recommendations of the white paper, Adams et al. [7] used the bending stiffness test from EN 14120:2003 as a starting point when developing one specifically for snowboarding wrist protectors. The bending stiffness test of Adam's et al. [7] measured the quasi-static bending stiffness of snowboarding wrist protectors when fitted on a wrist surrogate. The surrogate was mounted on a uniaxial test device, with a cable passing from the load cell around a pulley to the fingers slowly extending the wrist. The slope of the resulting torque–angle curve determined the bending stiffness of the protector.

Building on their prior work [7], Adams et al. [8] found the size and shape of the wrist surrogate to influence the

This article is a part of a Topical Collection in Sports Engineering on The Engineering of Sport 14 Conference held at Purdue University USA, edited by Dr Hugo Espinosa, Steven Shade, Dr Kim Blair, Professor Jan-Anders Månsson.

✉ G. Leslie
G.Leslie@mmu.ac.uk

[1] Musculoskeletal Science and Sports Medicine, Manchester Metropolitan University, Manchester M1 5GD, UK

[2] Advanced Materials and Surface Engineering, Manchester Metropolitan University, Manchester M1 5GD, UK

[3] Centre for Sports Engineering Research, Sheffield Hallam University, Sheffield S10 2LX, UK

---

[1] Stiffness of wrist protectors in EN 14120:2003.

measured bending stiffness of snowboarding wrist protectors. A geometric surrogate, based on anthropometric data, gave more consistent results than the surrogate from EN 14120:2003 and a hand and forearm based on a laser scan of a ~ 50th percentile male. A geometric wrist surrogate was subsequently implemented into a snowboarding wrist protector bending stiffness test within ISO 20320:2020.[2] ISO 20320:2020 also contains an 'Impact Performance' test, which is not considered here. The bend stiffness test in ISO 20320:2020 involves applying set torques to the fingers of the surrogate, and recording the wrist extension angles, which are required to lay within set ranges.[3] ISO 20320:2020 states that the force should be applied perpendicular to the fingers via a cord or cable around them but does not state a loading rate. Three tests shall be done on one sample (at the room temperature condition), and all must meet the pass requirements.

ISO 20320:2020 also states the wrist surrogate used for the bending stiffness test should be made of a polyamide or similar material. Recent work has reviewed the biofidelity (modelling the response of a human) of human body surrogates used for testing personal protective equipment, such as by incorporating compliant material to represent soft tissue [10–13]. The authors previous study [14] presented a 'compliant wrist surrogate', based on the geometry specified in ISO 20320:2020, consisting of a stiff core (nylon) and a 3 mm thick silicone outer layer to represent skin. The silicone outer layer increased the measured stiffness of wrist protectors in the bending stiffness test of Adams et al. [7, 8], relative to a comparable stiff surrogate (without silicone). Furthermore, the torque required to extend the wrist on both a compliant (with silicone) and a stiff (without silicone) surrogate increased with protector strap tightness, as found by Adams et al. [7] for a surrogate without silicone. Based on previous work, the stiffness of the protector is determined by strap tightness and surface compliance, and therefore, the measured bending stiffness is the stiffness of the system (surrogate–protector–strapping).

Repeatability of procedures is determined when tests are separated by time intervals, and a test–retest study has been conducted to assess the suitability of a device for measuring wrist joint angles in boxing [15] using the surrogate from EN 14120:2003. The previous work on bending stiffness testing of snowboarding wrist protectors [6–8, 14] conducted the tests during one session and did not assess the intra-operator repeatability. Therefore, this study investigated the intra-operator repeatability of a bending stiffness test for snowboarding wrist protectors. The purpose was to assess the repeatability of the bending stiffness test for both a stiff (ISO 20320:2020) and a compliant surrogate [14], with regard to test session and protector strapping condition. The hypothesise was, for a single operator, test session would not affect measured torque values of the bending stiffness test. Furthermore, it was expected that adding a skin simulant to an otherwise stiff surrogate would reduce the protector's sensitivity to both strapping condition and test session on torque values.

2 Methods

The same bending stiffness test method as Leslie et al. [14] was conducted, on three test sessions, each a week apart. The intention was not to exactly replicate the test in ISO 20320:2020, but to go beyond it, testing a wider range of loads and hence wrist angles, which could have implications for future revisions of the standard. Such revisions could include specific requirements for strapping condition, changes to the surrogate outer surface compliance, and how they may influence the required pass criteria. While the load was not applied perpendicular to the fingers, as stipulated in ISO 20320:2020, the equivalent load was calculated [7, 8, 14]. The torque values specified in ISO 20320:2020 for the medium sized surrogate fall within the load range tested here, and results are extracted and presented for the conditions specified in the standard.

All equipment was packed away at the end of each test session and re-setup at the start of the next one. The same test equipment, same two surrogates (compliant and stiff), and the same six protectors of each style (short and long, tested six times in the previous study) from Leslie et al. [14] were used in this study, so only a brief description of the test is described here. The wrist joint of both surrogates matched the description in ISO 20320:2020, as the hand and forearm sections were connected with a metal axle that did not resist flexion and extension. Differences between the test presented here and the one specified in ISO 20320:2020, as well as the work of Leslie et al. [14] are noted.

The wrist surrogate was fastened to a bespoke rig, and a metal cable (⌀ 2 mm) connected the distal end of the surrogate fingers to the load cell of a uniaxial test machine (Hounsfield HK10S tensometer fitted with a 1 kN load cell) (Fig. 1). Positive vertical displacement of the load cell applied a torque to the surrogate wrist, pulling the hand backwards and mimicking hyperextension. Before each test, the protector was fastened to the wrist surrogate, the finger clamp and cable were connected, and the 'start wrist angle' was measured with an inclinometer (PRO360, SPI, New York, USA). A linear displacement was then applied by the test machine at 200 mm/min, extending the wrist from the start angle (~ 40°) to the end angle of ~ 85° at ~ 1°/s, while recording load and

---

[2] Limitation of wrist extension in ISO 20320:2020.

[3] 50°–75° for the first torque of 5 Nm, increasing to 55°–80° for the second torque of 8 Nm, for the medium wrist surrogate.

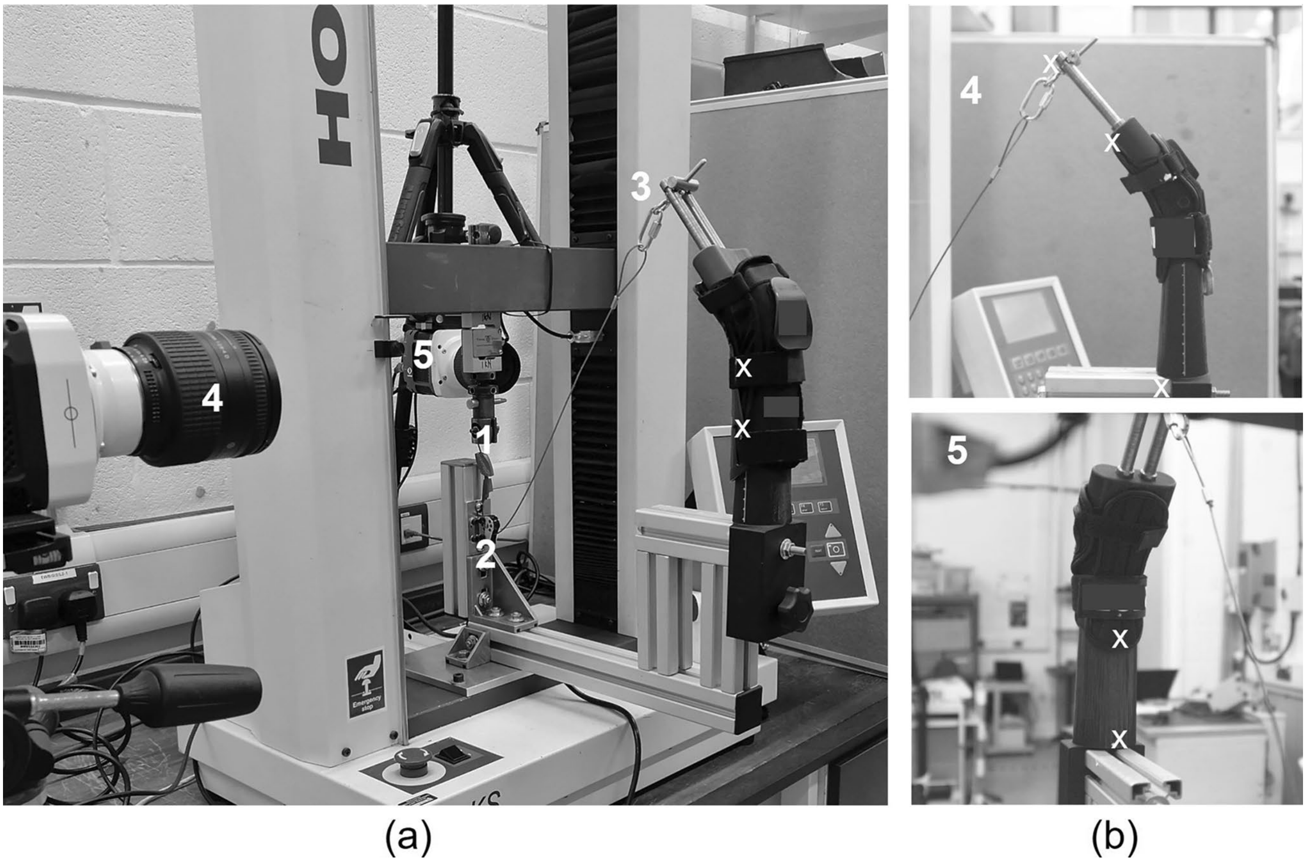

Fig. 1 Bending stiffness test setup with two cameras: **a** long protector on the stiff surrogate, **b** view from cameras for the short protector on the stiff surrogate (top—camera one, bottom—camera two). 1—cable to uniaxial test machine, 2—pulley, 3—finger clamp, 4—camera one viewing wrist extension, 5—camera two viewing dorsal side of protector. White crosses indicate the location of markers on the rig and protectors. See Online Resource 1 section starting 00:05 for a video from both cameras

displacement. Differences between the test specified in ISO 20320:2020 and one used here were (1) the use of a clamp to connect the cable to the fingers, (2) the load not being applied perpendicular to the fingers (as the cable passed around a pulley) and (3) temperature not being controlled.

Improvements made to the test protocol of Leslie et al. [14] included (1) introducing rest periods of at least 5 min between test repeats and at least 15 min between surrogates, to limit any effect of protector degradation, (2) increasing the maximum wrist extension angle to ~ 85° (previously ~ 80°), to create a wider measurement range, (3) adding a second camera viewing the dorsal side of the protector, synchronised with the side-on camera, to give more insight into any protector slippage (See Online Resource 1 section—starting 00:05 s for an example video from each camera), (4) adding markers to the protectors to measure protector movement in video footage from testing, and (5) reducing the mass of the clamp that connected the cable to the fingers, from 184 to 54 g.

Two protectors of each style (short, long) were tested for each strapping condition (loose, moderate, tight) and surrogate (compliant, stiff) (See Online Resource 1 section—starting 00:25 s for an example video of each surrogate–protector condition). Protector strapping condition was set by holding the surrogate horizontally and then hanging either a 1, 2 or 3 kg mass from the strap [7]. The surrogate was then rotated to secure the strap and the strap position was marked for future reference, as done before [7, 8, 14]. Three repeated tests (as per ISO 20320:2020) were performed for each protector–surrogate–strapping condition (total per test session = 72 tests) and repeated across three test sessions (total tests $n = 216$). Protectors were re-positioned and re-strapped between tests. The first test for each combination (24/72 tests per test session) was filmed with two synchronised cameras (Phantom Micro R111, Vision Research UK Ltd, Bedford, UK) fitted with a zoom lens (Nikon AF Nikkor 24–85 mm 1:2.8–4 D, Nikon Corporation, Japan). The cameras were set at a resolution of 1280 × 800 pixels and a capture rate of 24 Hz. The image scale (pixel/mm) for each camera was obtained manually from a known dimension on the surrogate. If protector slippage was observed, measurements were taken between a marker on the protector and a

Table 1 General linear model univariate between subject effects for the stiff surrogate and the compliant surrogate

Source	df_1	df_2	F	p value	Partial eta squared (η_p^2)
Stiff					
Protector	1	360	5567.23	<0.001	0.94 (large effect)
Angle	3	360	2241.99	<0.001	0.95 (large effect)
Strapping condition	2	360	813.38	<0.001	0.82 (large effect)
Test session	2	360	72.26	<0.001	0.29 (large effect)
Compliant					
Protector	1	360	3740.56	<0.001	0.91 (large effect)
Angle	3	360	1632.35	<0.001	0.93 (large effect)
Strapping condition	2	360	536.56	<0.001	0.75 (large effect)
Test session	2	360	106.17	<0.001	0.37 (large effect)

marker on the rig. Room temperature was recorded at the start and end of each test session, and the mean value for each session was calculated.

Load and linear displacement were recorded by the test device (capture rate of 25 Hz), and converted to torque and angle [7, 8, 14]. The mean and standard deviation (SD) of the torque values at 5° intervals from filtered torque vs. angle data were calculated [14]. The relationship between wrist angular extension and torque was studied for four cases: 50°, 55°, 75° and 80°. These four cases relate to each extremity of the pass criteria of ISO 20320:2020. General linear model (GLM) univariate analysis was performed using SPSS statistical software (IBM® SPSS® Statistics Premium 27) at a significance level of $p < 0.05$ to determine the main effects for each surrogate individually ($\eta_p^2 > 0.01$ small effect, $\eta_p^2 > 0.06$ medium effect, $\eta_p^2 > 0.14$ large effect [16]). Torque was set as the dependent variable and protector, angle, strapping condition, and test session as the independent variables. This statistical approach was chosen because it investigates the effect of individual independent variables, allowing all the data for each protector–surrogate–strapping condition to be input in one analysis.

3 Results

The mean room temperature for test session one, two and three was 20.6, 18.2 and 20.0 °C, respectively, all of which were within the room temperature condition in ISO 20320:2020 of 20 ± 2 °C.

The GLM univariate analysis showed test session had a significant ($p < 0.05$) effect on torque values for both surrogates, with a large effect size [$\eta_p^2 = 0.29$ (stiff), 0.37 (compliant)] (Table 1). Angle, protector and strapping condition also had a significant effect on torque values, as expected [7, 8, 14], with a large effect size. The effect of the hand angle and protector was marginal between surrogates (~ 0.025 difference in η_p^2), whereas the strapping condition had a slightly larger effect on the stiff surrogate than the compliant surrogate (0.07 difference in η_p^2), and the test session had a slightly larger effect on the compliant surrogate than the stiff surrogate (0.08 difference in η_p^2).

Torque values increased with both wrist extension and strap tightness (Fig. 2), as expected [7, 8, 14]. The compliant surrogate tended to give higher mean torque values for a given wrist angle than the stiff surrogate (see Figure S1 in Online Resource 2 for a comparison of mean torque at set angles). The long protector gave higher torque values for a given wrist extension angle than the short protector, again as expected [7, 8, 14].

When comparing the torque vs. angle results for the stiff surrogate with the requirements of ISO 20320:2020 (Fig. 2a, c), the short protector never met the pass criteria, and the long protector only met it at the tight strapping condition. When the protectors did not meet the pass criteria of ISO 20320:2020, this was because the surrogate–protector stiffness was too low.

Observations from the videos showed that protector slippage occurred. Slippage occurred on (1) the top of the dorsal side of the short protector (towards the surrogate fingers), (2) the bottom of the dorsal side of both the short and long protector (towards the base of the surrogate forearm), and (3) both straps of the long protector (see Online Resource 1 section—starting 00:46 s and Figure S2 in Online Resource 2). Although protectors appeared to slip less on the compliant surrogate than when on the stiff surrogate, the measured difference in protector slippage between surrogates was not significant ($p > 0.09$ in all cases) (see Table S1 in Online Resource 2 for statistical analysis).

4 Discussion

Test session had a large effect ($\eta_p^2 > 0.14$) on torque values for two snowboarding wrist protectors in a quasi-static bending test for both surrogates (0.29 η_p^2 stiff, 0.37 η_p^2 compliant surrogate), indicating the test was not repeatable (Table 1) in disagreement with the hypothesis. The similar effect size for test session between surrogates (0.29 η_p^2 stiff vs. 0.37 η_p^2 compliant surrogate) indicates that adding a skin simulant did not improve the consistency of torque values between test sessions, again in disagreement with the hypothesis. Despite this limited repeatability, torque increased with both wrist angle and strap tightness (Fig. 2), as reported before [7, 8, 14], indicating the overall

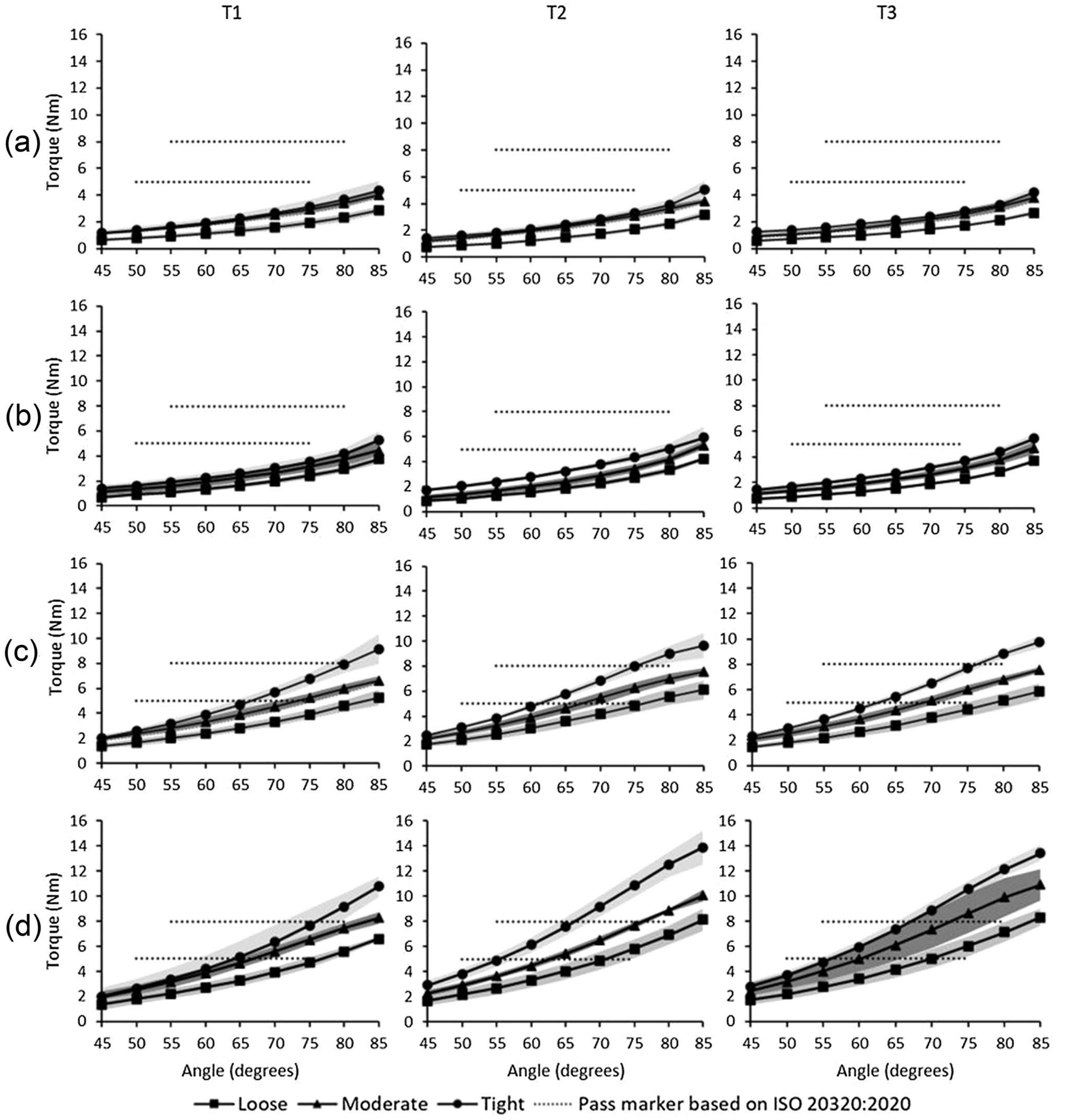

Fig. 2 Torque vs. angle results for the three test sessions (columns T1, T2, T3) and four surrogate–protector conditions: **a** stiff short, **b** compliant short, **c** stiff long, **d** compliant long. Shaded region indicates the SD. The dotted horizontal lines indicate the pass criteria for ISO 20320:20200 for the medium surrogate used here. Note only the surrogate–protector conditions with the stiff surrogate meet the conditions of the standard. See Online Resource 1 section starting 00:25 for a video of each surrogate–protector condition

trend of results was consistent. Adding a skin simulant to an otherwise stiff wrist surrogate increased the surrogate–protector stiffness, as found previously [14]. However, the magnitude of the change in stiffness could not be reliably quantified due to limited repeatability between test sessions.

The finding of limited test repeatability has implications in measuring the stiffness of snowboarding wrist protectors in a bending stiffness test. It may be possible to achieve improved repeatability with a test setup like the one used here by mounting the surrogate differently within a mechanical test device to remove the need for the cable and pulley arrangement (e.g. [17]). Indeed, it was hard to precisely set the start angle of the hand and ensure a consistent initial tension in the cable between tests. The start angle ranged by up to 4.1° [coefficient of variation (CoV) 2.5%] within protector–surrogate–strapping combinations, alongside a range in starting torque of up to 1.08 Nm (CoV 29.3%) (see Table S2 in Online Resource 2). These variations in hand angle and cable tension at the start of each test may have contributed to the low repeatability, particularly as the overall trends of results were consistent.

Strapping condition had a large effect ($\eta_p^2 > 0.14$) on torque values for both surrogates, but the effect was similar between surrogates (0.82 η_p^2 stiff vs. 0.75 η_p^2 compliant surrogate) (Table 1), indicating that adding the skin simulant did not reduce the protector's sensitivity to strapping condition, in disagreement with the hypothesis. This finding further highlights the need for the strapping condition to be controlled when testing wrist protectors on a surrogate, and ideally in ISO 20320:2020, such as a minimum strap tightness requirement. ISO 20320:2020 currently states that the protectors should be strapped as per the manufacturer's instructions. Requirements for what needs to be included in these instructions could be added in the first revision of ISO 20320:2020.

When on the stiff surrogate, the long protector only met the pass criteria of ISO 20320:2020 when tightly strapped. The implication of this finding is that whether protectors pass the standard could depend on how tightly the operator sets the straps. Even slight variations in strap tightness within a strapping condition could have influenced torque–angle relationships and reduced the test repeatability. Based on the results here and previous work, the effect of how protectors act to stiffen the wrist in use, is likely to depend on how tightly the protector is strapped. Future work could look to directly measure, and control, strap tightness, such as via pressure sensors mounted between the protector and surrogate, as done when assessing ski boot fit [18]. As both surrogate outer surface compliance and protector strapping condition influenced the torque–angle relationship, the pass requirements of bending stiffness tests within standards for wrist protectors should be considered in conjunction with the surrogate design and any prescribed strapping conditions. As the test defined in ISO 20320:2020 was not replicated exactly here, and testing was not conducted in a certified test house with new wrist protectors, the findings do not have direct implications on the certification of the products tested.

Both protectors slipped more on the stiff surrogate than on the compliant surrogate, as reported previously [14], but the measured differences in slippage were not significant. The second camera used here gave more insight into protector slippage of the long protector and other locations of the short protector. No further interpretation can be made on the effect of protector slippage on results. Future work could quantify how protectors move and slip when worn by participants as they flex their wrist with a view to ensuring these movements are replicated in the bending stiffness test, which may require modifying the surrogate design.

There are limitations to the present study. First, only intra-operator repeatability was assessed. Inter-operator and inter-lab repeatability could be the focus of future work. This study did not replicate the test prescribed in ISO 20320:2020 exactly, and thus the findings for repeatability do not apply directly to the standard. It is, however, likely that how tightly the operator straps the protector to the surrogate and their ability to apply each prescribed load via a cable perpendicular to the fingers will influence the results, and possible outcome, of that test. Future work should replicate the test in ISO 20320:2020 exactly, controlling the room temperature, directly measuring torque perpendicular to the fingers, and testing new protectors, with an aim to compare the repeatability of the test with the results presented here. If the test prescribed within ISO 20320:2020 also has poor repeatability, improvement strategies could include consideration about the strapping of the protectors, reviewing the number of repeats, and incorporating statistics. Given that there will always be variability in a test, acceptance criteria should be incorporated. As in previous work on this topic [7, 8, 14], the work presented here is limited to testing at room temperature, and future work should consider the cold condition of ISO 20320:2020 of -10 ± 2 °C. The work was also limited to slow bending of wrist protectors, which does not mimic how they must perform during a snowboarding fall, when the hand can be forced backwards rapidly. Recent work presented a test for assessing the impact performance of wrist protectors when fitted to a wrist surrogate made of stiff materials [19], and a more biofidelic surrogate, like the compliant one presented here, could be developed for that test scenario. Furthermore, understanding the influence of the loading rate of a bending stiffness test could be the focus of future work.

5 Conclusions

Test session significantly affected the measured torque values of a bending stiffness test for snowboarding wrist protectors, indicating the test had limited repeatability. Despite this limited repeatability, the overall trend of results between the various test conditions (surrogate, protector, strap tightness) was consistent. Adding a skin tissue simulant to an otherwise stiff surrogate did not reduce the protector's sensitivity to both strapping condition and test session on torque values. Future work should look to improve the repeatability of tests for measuring the bending stiffness of snowboarding wrist protectors.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s12283-022-00397-y.

Acknowledgements We would like to thank Manchester Metropolitan University for funding this research, the technicians for fabricating the rig, and Lizzie Adshead for assistance during testing.

Data availability Data is available upon request.

Declarations

Conflict of interest The authors were involved in the development of ISO 20320:2020. Tom Allen is the Editor-in-Chief of Sports Engineering, and he was blinded from the peer-review process for this article.

References

1. Michel FI, Schmitt KU, Greenwald RM, Russell K, Simpson FI, Schulz D, Langran M (2013) White paper: functionality and efficacy of wrist protectors in snowboarding-towards a harmonized international standard. Sports Eng 16(4):197–210
2. Kim S, Endres NK, Johnson RJ, Ettlinger CF, Shealy JE (2012) Snowboarding injuries: trends over time and comparisons with alpine skiing injuries. Am J Sports Med 40(4):770–776
3. Idzikowski JR, Janes PC, Abbott PJ (2000) Upper extremity snowboarding injuries: ten-year results from the Colorado snowboard injury survey. Am J Sports Med 28(6):825–832
4. Pierpoint LA, Kerr ZY, Crume TL, Grunwald GK, Comstock RD, Selenke DK, Khodaee M (2020) A comparison of recreational skiing-and snowboarding-related injuries at a Colorado ski resort, 2012/13-2016/17. Res Sports Med 28(3):413–425
5. BS EN ISO 20320:2020 (2020) Protective Clothing for Use in Snowboarding—Wrist Protectors—Requirements and Test Methods. ISO: Geneva, Switzerland
6. Schmitt KU, Michel FI, Staudigl F (2011) Analysing the impact behaviour of recent snowboarding wrist protectors. In: Ircobi conference 2011. pp 51–61. Krakow
7. Adams C, James D, Senior T, Allen T, Hamilton N (2016) Development of a method for measuring quasi-static stiffness of snowboard wrist protectors. Procedia Eng 147:378–383
8. Adams C, James D, Senior T, Allen T, Hamilton N (2018) Effect of surrogate design on the measured stiffness of snowboarding wrist protectors. Sports Eng 21(3):217–225
9. BS EN 14120:2003 (2003) Protective clothing—wrist, palm, knee and elbow protectors for users of roller sports equipment—Requirements and test methods. European Committee for Standardization, Brussels
10. Payne T, Mitchell S, Halkon B, Bibb R, Waters M (2016) Development of a synthetic human thigh impact surrogate for sports personal protective equipment testing. Proc Inst Mech Eng Part P J Sports Eng Technol 230(1):5–16
11. Maurel ML, Fitzgerald LG, Miles AW, Giddins GE (2013) Biomechanical study of the efficacy of a new design of wrist guard. Clin Biomech 28(5):509–513
12. Ankrah S, Mills NJ (2004) Analysis of ankle protection in association football. Sports Eng 7(1):41–52
13. Ankrah S, Mills NJ (2003) Performance of football shin guards for direct stud impacts. Sports Eng 6(4):207–219
14. Leslie G, Wang W, Winwood K, Liauw C, Hamilton N, Allen T (2020) Effect of surrogate surface compliance on the measured stiffness of snowboarding wrist protectors. Multidiscip Digit Publ Inst Proc 49(1):84
15. Gatt IT, Allen T, Wheat J (2020) Accuracy and repeatability of wrist joint angles in boxing using an electromagnetic tracking system. Sports Eng 23(1):1–10
16. Richardson JTE (2011) Eta squared and partial eta squared as measured of effect size in educational research. Educ Res Rev 6(2):135–147
17. Hermann A, Ostarhild J, Mirabito Y, Bauer N, Senner V (2020) Stretchable piezoresistive vs. capacitive silicon sensors integrated into ski base layer pants for measuring the knee flexion angle. Sports Eng 23(1):1–10
18. Fontanella CG, Arduino A, Toniolo I, Zampieri C, Bortolan L, Carniel EL (2021) Computational methods for the investigation of ski boots ergonomics. Sports Eng 24(1):1–14
19. Adams C, Allen T, Senior T, James D, Hamilton N (2021) Impact testing of snowboarding wrist protectors. Proc Inst Mech Eng Part P J Sports Eng Technol 0(00):1–12