Fall detection in snowboarding - Sensing forces on wrist protectors

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***Abstract*—The wrist is the most often injured body part caused by snowboard accidents. Due to the short occurrence of very high g forces, fractures are not unusual. Studies have already established the protective effect of protectors. Unfortunately, there is still no standard that these protectors have to meet. In this study, the impact of protectors on a fall will be researched in more detail. For this purpose, a fall simulator is created with which a fall is simulated under real conditions as far as possible. It simulates the forces that affect the wrist during a fall. The data is recorded using two measuring devices. One of them is the STEVAL-STLKT01V1 sensor kit from ST Microelectronics. It is used in a similar way to a smartwatch on the wrist. The sensor is triggered by the jerk, which is calculated from the acceleration sensor data. The second measuring device is a force plate. This records the impact forces of the fall simulator. Falls from relative heights of 30, 50 and 70 cm are measured. Three different size models and the associated changes in the forces are assessed. With the wrist sensor, it was found that both the frequency and the measuring range are not sufficient to provide accurate data. The data thus obtained can only serve as a rough guide. The data from the force plate, on the other hand, was usable and thus it was possible to establish meaningful relationships between the adjusted variables. The protectors used have a significant influence on the forces acting on the wrist. The difference between wrist guards for inline skaters/skateboarders and snowboarders can also be seen. Even if this is not always significantly different. But especially in the case of the different force absorption for normal and parallel forces a different standard should be established for the snowboard wrist guards compared to the existing standards for inline skating. Furthermore, an important finding is that the angle of impact of the hand has a significant influence on the force applied to the wrist. The findings of this study provide the basis for further specific tests for the individual factors influencing falls. Furthermore, a larger test series for different protectors can be carried out and the advantages and disadvantages of the individual protectors can be examined more closely.**

***Index Terms*—snowboarding, fall detection, wrist, protector, sensor.**

I. Introduction

SINCE the 70s, snowboarding has become an integral part of winter sports. It thus became part of the Olympic Games in 1998 and became more and more popular [1]. Snowboarding combines aspects of skiing, surfing and skateboarding. The number of riders is estimated at around 10 to 15 million. These are essentially adolescents and young adults [2]. Like in other sports, accidents are absolutely normal in snowboarding. For that reason, several types of protectors are developed. More than 90 per cent of winter sports enthusiasts wear a helmet when practising their sport. It has also been proven that they offer more safety to the user [3], [4]. Apart from head injuries, snowboarding involves several regions that are affected in the event of a fall. The impact of protectors for these body parts is still not fully researched. It was determined that compared to alpine skiing, the risk of injuries to the upper body is higher in snowboarding [5]. Injuries to the wrist with resulting fractures are the most common type of injury for snowboarders [6], [7], [8]. According to [9], wrist and upper body cover 35 to 45 percent of snowboarding accidents. This is caused by the fact that most of them try to absorb the fall with their arms. Thus, an axial pressure force acts on the bent wrist joint (extension). If the force is too high, this leads to a forearm bone fractures or/and hyperextension of the wrist joint (ligament sprains) [10], [11]. Especially when falling backwards, most injuries happen. The study [6] came to the conclusion that twice as many fractures occur here than when falling forwards.

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A. Wrist guard validation

The effectiveness of wrist protectors has already been confirmed in a meta-analysis [9]. The basic purpose of the wrist protectors is to (1) reduce peak impact forces (2) absorb the impact energy and (3) prevent over-extension [12], [13]. It is still unclear which properties determine how good protectors are. There are already several studies that have looked at the properties of wrist protectors (especially for snowboarders), as can be seen in Table I.

TABLE I
OVERVIEW OF THE STUDIES THAT CARRY OUT TESTS WITH WRIST PROTECTORS. PARTIALLY SUMMARISED BY [14]

Source	Experimental setup	Effective mass
[15]	Bending test	500 N
[16]	Bending test	1, 2 and 3 kg
[17]	Drop test, bending test	2,5 kg; 3 Nm
[18]	Dummy arm; drop test	∼1.8 kg
[19]	Model	∼14 kg (bilateral; 20% BW)
[20]	Volunteers; pendulum arrest test	1.7 kg
[21]	Volunteers; simulated falls	∼3.75 kg (bilateral; 5% BW)
[22]	Cadavers; drop test	23 kg
[23]	Cadavers; drop test	16 kg
[24]	Cadavers; drop test	9 kg

In doing so, most of the studies are orientated to the European standard EN 14120:2003, which prescribes the requirements for roller sports wrist protectors.

B. Occurring forces during falls

The load required to cause a fracture is between 2 - 2,5 kN [17], [22], [23], [24]. To illustrate the process of a fall, [14] had simulated falls with the help of volunteers. They had to fall on their outstretched arm. In doing so, she read out relevant parameters such as impact forces, impact angle, impact velocity, force distribution. Another study [25], which determined forces during falls by means of test subjects, found that the maximum force occurring during backward falls (313 N) was significantly (p = 0.038) higher than during forward falls (225 N). This was in contrast to the wrist extension moment, where no significant difference was found (p = 0.091). No injuries occurred among the 128 test subjects in this study. The study also investigated the influence of age and experience on the maximum impact force that occurs. A distinction was made between adults, persons older than 17 years and the rest ($\leq$17 years). The younger age group achieved a lower impact force (222 N) than the adults (314 N). It was also noticeable that in the younger age group, the experienced riders had a lower occurring force (213 N) than beginners (266 N). The maximum extension that occurred during the impact was 80.2 ± 15.8° distributed over all participants. In general, the normal physiological wrist range of motion is 60 - 82° for wrist flexion and 60 - 75° for wrist extension [26], [27], [28], [29].

C. Previous boundary conditions for protector validations

In the two studies [17] and [14], boundary conditions have already been established which the test procedures and protectors should fulfil in each case. These points were used as orientation for the test set-up.

- "Forward and backward falls can be approximated by the same loading conditions in a test standard." [14]
- "The effective mass (unilateral) representing the mass acting on the wrist can be estimated by a few kilograms. In this study, a range of about 2–3 kg was identified. In the context of snowboarding, a range of 3–5 kg is suggested as a 'worst-case' assumption to cover more severe impacts than those mimicked here." [14]
- "An impact angle of the forearm relative to the ground (in sagittal plane) of 758 seems to be a reasonable approximation." [14]
- "The impact velocity is assumed to be approximately 3 m/s." [14]
- "The alignment of the hand with respect to the forearm during touchdown is kinematically defined. The data presented here can be useful for developing a forearm–hand prosthesis as a test device for application in a dynamic performance test." [14]
- The maximum peak force applied to the wrist should be <3 kN. As mentioned in chapter A, this value lies in the range in which a fracture occurs [17].
- The maximum extension of the wrist should be <80° and a minimum of >30° (for relaxed wearing comfort) [17]

In this paper, an attempt was made to develop an experimental set-up with which the forces which occur during an fall can be measured. The influence of wrist protectors and size differences of the body should then be included. Important for this is finding a useful measurement method with a sensor at the wrist and creating an appropriate testing machine. The test equipment is then to be used for several fall variants and protectors.

II. Methods

The focus of this work is on two main points. The first is to create a usable test device to simulate falls on the wrist. The second is to perform a series of laboratory tests to (1) correctly determine the threshold for the wrist sensor (2) compare the impact force data for different protectors and fall variants (fall height).

A. Fall simulator

The aim was to build the fall simulator in such a way that it simulates a real fall as closely as possible. To make this possible, it should also be adjustable for different bodies and fall sizes. Basically, the test setup as shown in picture 1 imitates a human falling over forwards or backwards.

Both the joint and the size can be adjusted quickly and easily. Only the length of the arm is not adjustable. An extra piece would have to be cut for each size. The attempt to make the arm with several joints (shoulder and elbow) and special lengths for the forearm and upper arm unfortunately failed. The joints cannot be reliably set equally tight after each attempt and would falsify the result. When the apparatus is released by pulling the pin (point 1 in figure 1), the front part of the constrictor tilts forward until impact occurs. The attached hand (see point 5 in figure 1) absorbs the entire fall. Depending on the adjustment, the force plate measures how much of the total weight is carried by the hand. All in all the part of the fall simulator who is in motion weights 5,34 kg
When setting the sizes, the anthropometric data of the European human from [30] was initially used. In addition, tests are to be made with the average height of the Austrians (male and female) by [31]. The sizes used for this can be found in the following Table:

TABLE II
OVERVIEW OF THE LENGTH RATIOS USED IN THE EXPERIMENT

	Height	**Shoulder height**	**Arm length**
European human	171,9 cm	142,4 cm	71,7 cm
Austrian man	178 cm	147 cm	71,7 cm
Austrian woman	166 cm	137 cm	71,7 cm

The shoulder height is taken proportionally from the European human. All test series are carried out with the same weight and the same arm length. The measurement for the unextended arm results from the angles for shoulder and elbow were worked out by [2] combined with the length from [30]. The distribution of the weight will be different due to the changed shoulder height. Since the wrist bends upwards each time after the simulation of a fall, it must be realigned each time. This flat was positioned in such a way that it rested flat on the impact surface. Care must also be taken to use a cord that does not expand differently each time it is stretched, thus

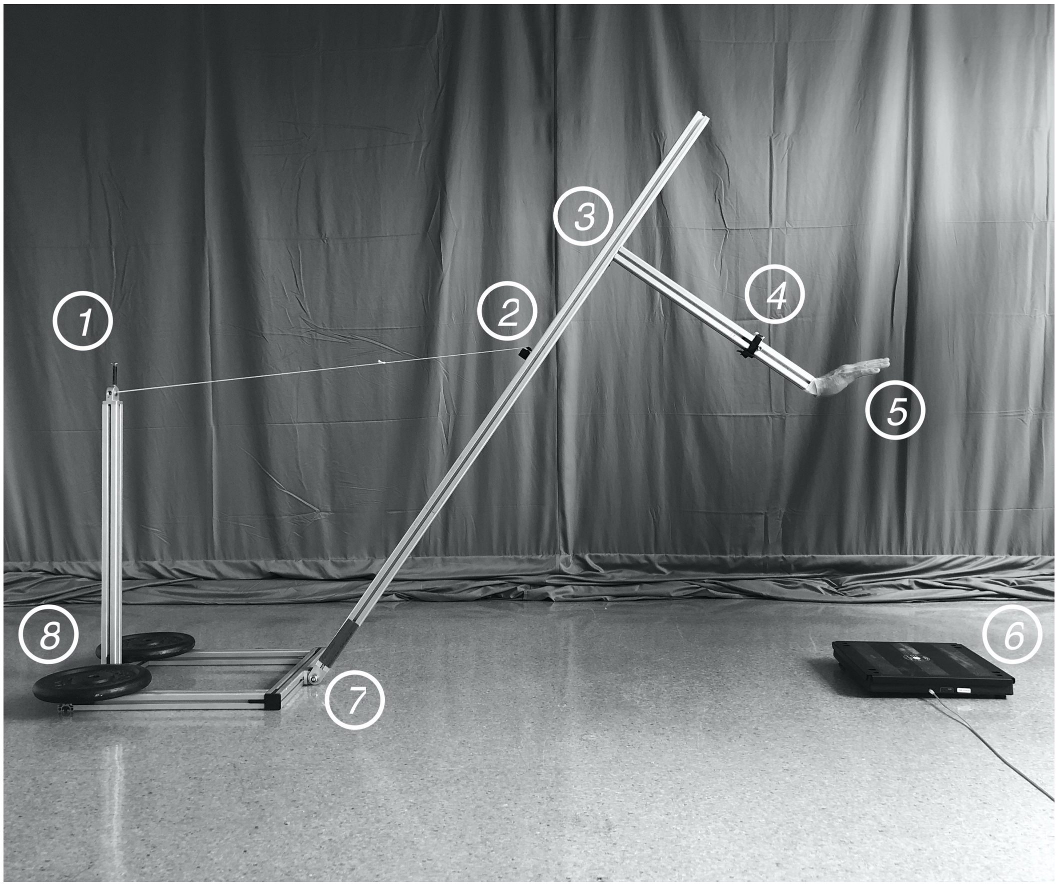

Fig. 1. Basic structure of the drop simulator: (1) Pull-out pin for releasing the apparatus (2) Attachment of the cord to the drop body, can be adjusted in height in order to set the respective drop height (3) Attachment of the arm in the respective height (AF, EH, (4) Attachment of the wrist sensor (5) Wrist and hand at an angle of 45° (6) Force plate on which the hand is to fall centrally (7) Joint around which the drop body falls, height from the ground 20 mm (8) Weights (20 kg) to prevent the construction from falling over.

changing the height of the fall slightly. The design must also ensure a quick and clean release. The pin used here around which the rope is tensioned can otherwise contribute vibration to the falling body shortly before it is released, which has an effect on the measurement results. The wrist sensor is placed at a distance of ca. 500 mm from the back of the fall simulator. It is held in place by two screws on the side. These are screwed into the frame (arm) and the sensor band cannot slip too much.

B. Wrist sensor

One of these devices which were used to detect a fall is the SensorTile development kit (STEVAL_STLKT01V1) from STMircoelectronics. This is equipped with the sensors listed in table III and shown in figure 2. This device was chosen because two other projects have already been implemented at the MCI. In Project [32], it was used to record and evaluate the catching of footballs. In Project [33], the strokes of a tennis player were also recorded and analysed. It is designed to be worn on the wrist like a smartwatch. The sensors have already been soldered to the SD slot and then housed in a transparent plastic case. This can then be attached to the arm by means of a rubber band which can be closed with Velcro.

The sensor was programmed using the programme Keil µVision, a C compiler. The collected data stored on the SD card was converted using a Python programme. An Excel table and plots were created for each fall.

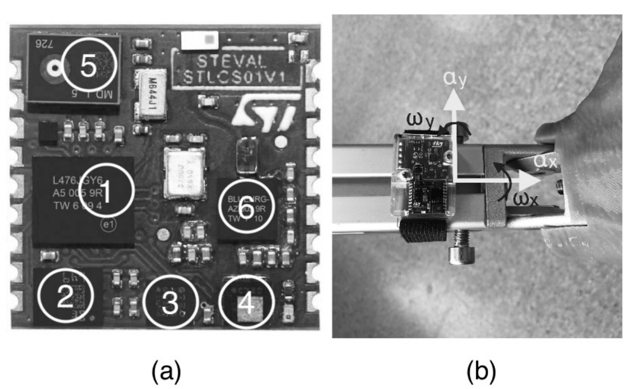

Fig. 2. Illustration of the STEVAL-STLCS01V1 (SensorTile) (a) The 13.5 x 13.5 mm grope board with the sensor markings from Table III [34]. (b) Shows the complete wrist sensor assembly and correct placement on the Fall Simulator. The axes indicate the orientation in which the sensor records them. The indicative values are those of the accelerometer α_x, α_y, and the gyroscope ω_x, ω_y.

TABLE III
STRUCTURE OF THE WRIST SENSOR AND INDICATION OF THE BANDWIDTH OF EACH COMPONENT

No.	Experimental setup	Range	Description
1	STM32L476JG		Microcontroller unit
2	LSM6DSM	±16 g	3DOF accelerometer
2	LSM6DSM	±1000 °/s	3DOF gyroscope
3	LSM303AGR	±5 mT	3DOF magnetometer
4	LPS22HB	260 – 1260 hPa	Pressure sensor
5	MP34DT05-A	0–122.5 dbSPL	MEMS microphone
6	BlueNRG-MS		BlueTooth

When adjusting the sensor, it was important to ensure that it can record with the highest frequency. This is to ensure that the maximum occurring force is recorded accurately. In order to use the storage capacity efficiently, the sensors should not continuously store all data on the SD card. A trigger should be selected which detects when a fall has occurred. Once this has been done, the data recorded 500 ms seconds before and after the fall should be saved on the SD card.

It is important to choose a suitable trigger. First, the relevance of the individual sensors was considered. One option here is audio recording. This would make sense in a laboratory test. Since no further ambient noise would be present or could be minimized. However, this does not make sense in the application of field tests for which this sensor is to be prepared in this work. The sensor would be located in the glove, which would make it difficult to record the sound. Furthermore, snowboarding involves a much higher noise level and the trigger could therefore be triggered incorrectly more often. However, no tests could be carried out to confirm these assumptions.

A combination of gyroscope and accelerometer is already being used in several studies to record falls [35], [36], [37]. In this case, the data are usually recorded on the upper body. Significantly higher g forces are expected for the wrist. This is based on the assumption that the wrist cannot be cushioned as much as the upper body. The assumption that significantly higher g forces act at the wrist would make it much easier to detect falls accurately. Since the gyroscope usually has to be used as a further identification factor for the low values that occur in the upper body. In general, the studies show that high acceleration data occur during a fall. Here, the absolute value of the acceleration data is determined by means of formula 1.

$$|\alpha_{abs}|(n) = \sqrt{(\alpha_x(n) + \alpha_y(n) + \alpha_z(n))^2} \tag{1}$$

The jerk can then be calculated from the data obtained using the formula 2.

$$j(n) = \frac{|\alpha|(n) - |\alpha|(n-1)}{t_1} \tag{2}$$

Here, the absolute value of two samples derived over time is compared with each other. $t1$ is the time interval between the samples used here.

The data from the pressure sensor was not considered relevant or useful in this work from the outset and was therefore not considered further. The magnetometer data is disregarded due to its low frequency (100 Hz).

C. Force plate

The force plate is the "2-Axis Force Platform" from Pasco as shown in figure 3 which has a size of 35 x 35 cm. The height is variable because the plate can be adjusted to compensate for inclined surfaces. In the laboratory, the plate was set to a height of 5.5 cm. It can be used to measure forces in two different directions. Normal to the plate and parallel to it. The various measurement options include static forces, such as when standing on the plate, but also dynamic vertical forces that occur when moving or jumping on it. Both possibilities are used in this work. The plate should be placed on a solid, level surface when in use in order to achieve the best possible measurement results. The platform must be aligned so that the hand is as central as possible on the plate. The software used to evaluate the data is called "DataStudio". The trigger and the recording conditions can be selected using the software. It is also recommended choosing the highest possible frequency. This is 1 kHz. A certain Newton value is set as the trigger (200 N). When this is reached, the software stores the forces measured 0.2 seconds before and 0.8 seconds after the impact. In total, the plate can measure up to 4400 N. On the one hand, the plate is used to determine the weight of the hand when it is placed on the plate. This varies depending on the size set, as the weight is distributed between the hand and the joint. Secondly, the impact force of the wrist is measured normal and parallel to it.

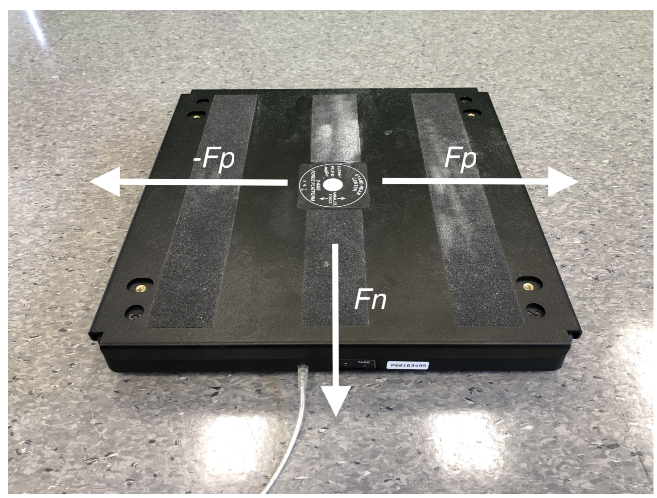

Fig. 3. Force plate: Arrows show in which directions the forces are absorbed (Fn = normal force; Fp = parallel force). The drop structure falls in the longitudinal direction to the parallel forces Fp.

D. Wrist guards

1) The hand: The original idea was to have the hand 3D printed. For this, a material should be used that is not too rigid and therefore does not break when it hits the ground. Therefore, thermoplastic polyurethane, or TPU for short, should be used. This material resembles a rubber-like state which brings with it the elastic properties that the hand should have. The model of the hand was freely available on the website of Thingiverse[1]. The search was for an outstretched hand that

[1]https://www.thingiverse.com/thing:1680395https://www.thingiverse.com/thing:1680395

was as anatomically similar as possible to that of a human being. When printing the hand, however, it was precisely these characteristics that led to problems. The material warped and thus no clean print was achieved. The reason for this may be the large structure of the hand. As a result, the plastic did not cool down quickly enough. Both the print from the wrist to the fingertip and the print attempt from the palm to the back of the hand failed. It was then decided to print a negative mold of the hand and then cast it. In the mould, which was 3D printed, space was made for the screw to be attached. For this "TASK 16" from SMOOTH-ON was used, which is an urethane that impressed with its tear resistance, impact strength and durability. The mixture is poured into the mould and then waits for a processing time of 90 minutes at room temperature. The thin mould was then removed and the hand was finished as can be seen in figure 4.

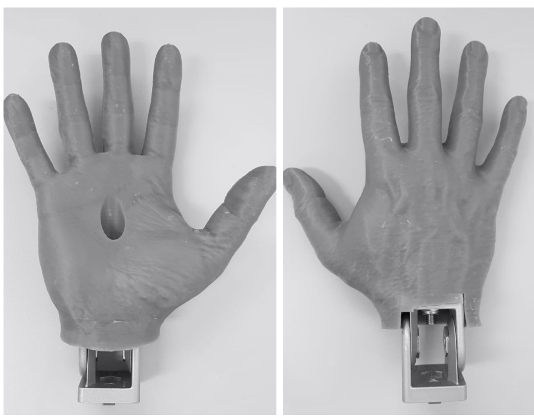

Fig. 4. Urethane cast hand which is screwed to the joint through the palm of the hand in the direction of the wrist.

2) Inline wrist guard: The REKD Pro wrist protector was chosen as the inline protector as you can see in the figure 5. This offers "360 ° all-round protection" as described by REKD[2].

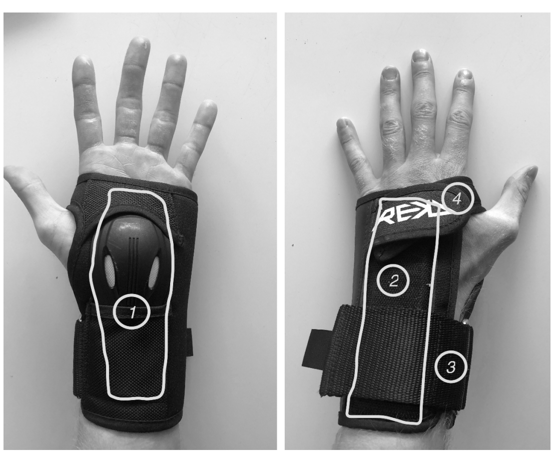

Fig. 5. Inline hand protector: (1) Protective shell (2) Shock-absorbing 6 mm thick foam padding (3) Strap to attach to wrist (4) Strap to attach to palm

On the palm side there is a protective cap and rails made of polypropylene (see point 1 in figure 5). This is padded with velvet lining which also absorbs the fall and provides a comfortable feel. On the back is a shock-absorbing 6 mm thick ethylene vinyl acetate (EVA) memory foam padding measuring 4 x 14 cm, which is designed to limit wrist bending (see point 2 in figure 5). On top of this padding is the Velcro fastener to which the two straps with safety tabs are attached to ensure a firm hold. On the sides there are additional parts made of abrasion-resistant PU leather. This wrist protector is available in 3 different sizes and has been used in the largest size L. The cost of this protector is 24.95 euros.

3) Snowboard wrist guard: The snowboard wrist protector WEDZE is made by Dreamscape. As you can see in picture 6, the outer appearance is similar to that of an inline or skating wrist protector.

Fig. 6. Snowboard wrist protectors: (1) 0.7 mm thick impact protection on the palm of the hand (2) Strap for fastening (3) Shell to protect against wrist bending

This protector is worn under the glove when snowboarding. The protector is tested according to the EN14120 standard and the distributor Decathlon[3] also assures that all products of the offered brand Dreamscape are additionally tested by them under realistic conditions (snow, cold, etc.). The outer composition of the protector consists of a 100 % polypropylene (PP) lining and a 100 % ethylene vinyl acetate (EVA) filling. The additional webbing (point 2 in figure 6) which ensures a firm hold of the protector is made of polyester. The protective part of the protector consists of two components. The first (point 1 in figure 6) is a padding in the palm area which is made of Nitrex foam. This is about 0.7 cm thick. This is to cushion the impact of the fall. The second component is the polymide shell with a size of 5 x 18 cm on the back of the protector (point 3 in figure 6). This is to limit the bending of the wrist as much as possible. In terms of price, this protector is in the lower category with its 14,99 euros. The protector is available in 4 different sizes and was chosen in XL.

[2]https://www.skatepro.at/116-36896.htmhttps://www.skatepro.at/116-36896.html

[3]https://www.decathlon.at/handgelenkschoner-snowboard-id$_8375045.htmlhttps://www.decathlon.at/handgelenkschoner-snowboard-i$

III. Results

For the size variant of the European human, multiple test variants were carried out. Simulations were made without, with inline protector and with snowboard protector. This was then done over a relative fall height of 30, 50 and 70 cm. Since the force plates themselves were 5.5 cm high, these were then added to the respective heights. In the second set of experiments, the size ratios of Austrian male and female were used. Only falls from a height of 30 cm were made and compared with each other. The influence of the size of the users was to be examined more closely. In all cases, 20 attempts were carried out.

First, however, some tests were carried out to find out what range of data sets could be expected and what they would look like. This was then used to select the threshold for the laboratory tests. This was relatively easy to choose because of the good conditions in the lab. That means that the sensor does not have to record any movement other than falling and does not have to record the forces of normal snowboarding as in field tests.

Due to the use of the flexibly insertable wrist, very inconsistent data sets were created. It was therefore decided to replace this with a 3D printed wrist. This joint was fixed and had an angle of 45°. The data obtained was normally distributed.

The resultant force and angle is calculated from the normal force and the parallel force. It thus shows the maximum effective total force and at what angle to the wrist this occurs as can be seen in figure 7. As the acceleration data was unfortunately not within the measuring range of the sensor, it was not evaluated further. Nevertheless, the respective jerk that occurs in the x and z axis was taken into account. The mean values with their standard deviation of the respective data were recorded in the following Tables.

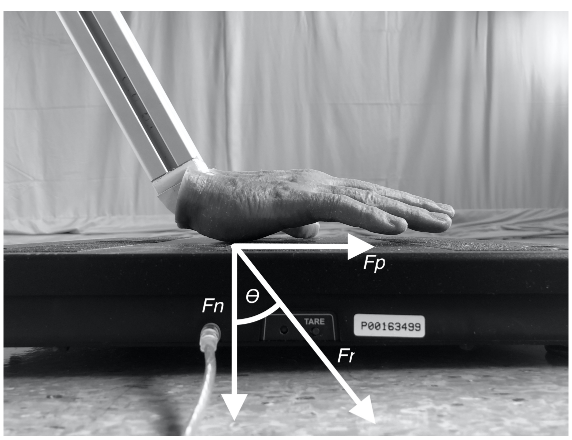

Fig. 7. Representation of the impact force. Fp = parallel force, Fn = normal force, Fr = resulting force, θ = angle of resultant force.

A. Correlation of the fall height

The correlation of certain values is to be described here. The values of the force plate (normal force and parallel force) are determined. One factor are the different heights of the fall, for which the height of the European human was used. The resulting correlation coefficient r for the fall heights of 30 cm, 50 cm and 70 cm:

TABLE IX
Correlation coefficient r for the different fall heights

Protector:	Normal force (r):	Parallel force (r):
None	0.99	0.98
Inline	0.98	0.95
Snow	0.98	0.96

There is a clear strong positive correlation with the height of fall for both the normal force and the parallel force. That is recorded for all three protectors.

B. Correlation of the shoulder height

Furthermore, the correlation coefficient between the different shoulder heights should be recorded. These were at 137 cm, 142,4 cm and 147 cm:

TABLE X
Correlation coefficient r for the different shoulder heights

Protector:	Normal force (r):	Parallel force (r):
None	-0,59	-0,32
Inline	0,92	-0,70
Snow	0,61	-0,73

The calculation of the potential energy had already shown that the potential energy at the starting point decreases if the drop height remains the same but the shoulder height increases. The associated negative correlation was not surprising, as it only occurs slightly with both normal and parallel forces (hardly significant). The calculations of the kinetic energy at impact height showed that the higher the shoulder height (at constant fall height), the lower the angular velocity. The negative correlation coefficient of the parallel force is in the significant range of about -0,7 with the use of both protectors. Why the coefficient of the normal force suddenly pointed in the positive direction and also in the significant range of 0,91 for the inline protectors and slightly significant for the snowboard protectors with 0,61 required a new analysis of the construction. It was found that the angle of impact of the hand to the ground changes. The higher the shoulder height, the flatter the impact of the hand on the ground, since the angle of impact increases with a higher shoulder height and the same arm length and drop height. The impact of the protector on the force plate is the more punctual and/or poorly distributed on the protector, the higher the impact is in the palm of the hand.

The angles of the applied resultant force can also be determined from the tables IV, VII and VIII. It can be seen that the angles (AF = 18,18°; EH = 18,97; AM = 18,16°; r = 0,01°) do not change significantly when no protector is used, so that in principle the expected impact forces decrease slightly and significantly with increasing shoulder height. However, when the protectors are used, the impact angle changes significantly for both inline protectors (AF = 14,69°;

TABLE IV
MEAN VALUES AND STANDARD DEVIATION FOR THE EUROPEAN HUMAN FROM A RELATIVE DROP HEIGHT OF 30 CM.

Body Size:		**Eurpean Human**	
Relative fall height:		**30 cm**	
Protector:	**None**	**Inline**	**Snowboard**
Normal force (N):	2522.17 ± 45,41	2589,79 ± 30,36	2129,92 ± 47,86
Parallel force (N):	866.92 ± 21,99	551,35 ± 16,70	556,24 ± 16,46
Resulting force (N):	2667,07 ± 46,01	2647,87 ± 31,38	2201,38 ± 49,78
Angle θ (°):	18,97 ± 0,45	12,02 ± 0,32	14,64 ± 0,24
Jerk x-axis	176295,7 ± 54326,77	136281,2 ± 27010,9	76048,8 ± 11232,1
Jerk z-axis	189280,0 ± 28653,6	199148,9 ± 22877,4	191825,8 ± 18797,7

TABLE V
MEAN VALUES AND STANDARD DEVIATION FOR THE EUROPEAN HUMAN FROM A RELATIVE DROP HEIGHT OF 50 CM.

Body Size:		**Eurpean Human**	
Relative fall height:		**50 cm**	
Protector:	**None**	**Inline**	**Snowboard**
Normal force (N):	3324,33 ± 58,37	3520,67 ± 95,46	3120,93 ± 45,07
Parallel force (N):	1056,63 ± 36,18	667,79 ± 23,78	795,81 ± 19,74
Resulting force (N):	3488,33 ± 61,96	3583,51 ± 95,74	3220,85 ± 45,46
Angle θ (°):	17,63 ± 0,49	10,74 ± 0,36	14,31 ± 0,34
Jerk x-axis:	104991,5 ± 16940,4	159533,2 ± 32508,4	117614,9 ± 7877,3
Jerk z-axis:	234000,8 ± 28889,3	218366,5 ± 32652,3	229107,49 ± 37167,3

TABLE VI
MEAN VALUES AND STANDARD DEVIATION FOR THE EUROPEAN HUMAN FROM A RELATIVE DROP HEIGHT OF 70 CM.

Body Size:		**Eurpean Human**	
Relative fall height:		**70 cm**	
Protector:	**None**	**Inline**	**Snowboard**
Normal force (N):	4073,89 ± 133,75	4002,59 ± 77,01	3777,39 ± 160,89
Parallel force (N):	1293,98 ± 47,64	773,86 ± 41,94	920,63 ± 48,74
Resulting force (N):	4274 ± 139,67	4076,84 ± 81,21	3888,14 ± 163,50
Angle θ (°):	17,62 ± 0,34	10,94 ± 0,46	13,70 ± 0,58
Jerk x-axis:	181265,8 ± 34082,4	207715,3 ± 47793,2	82671,9 ± 16372,3
Jerk z-axis:	257681,8 ± 40310,8	260082,4 ± 33255,6	214234,6 ± 36085,3

TABLE VII
MEAN VALUES AND STANDARD DEVIATION FOR THE AUSTRIAN MALE FROM A RELATIVE DROP HEIGHT OF 30 CM.

Body Size:		**Austrian Male**	
Relative fall height:		**30 cm**	
Protector:	**None**	**Inline**	**Snowboard**
Normal force (N):	2518,12 ± 83,26	2707,56 ± 71,32	2235,80 ± 18,84
Parallel force (N):	826,78 ± 68,08	548,31 ± 47,58	540,87 ± 11,95
Resulting force (N):	2650,89 ± 93,43	2762,77 ± 76,88	2300,32 ± 18,97
Angle θ (°):	18,16 ± 1,15	11,44 ± 0,78	13,60 ± 0,29
Jerk x-axis:	126869,1 ± 15370,6	104056,6 ± 24015,1	72369,6 ± 10986,2
Jerk z-axis:	201326,9 ± 36672,1	178498,3 ± 27652,2	200524,8 ± 28423,9

EH = 12,02°; AM = 11,44°; r = -0,89) and snowboard protectors (AF = 15,53°; EH = 14,64°; AM = 13,60°; r = -0,91). It should be noted that the angle is only the direction of the resulting force and not the angle at which the hand hits the ground.

IV. DISCUSSION

This work had several objectives. One of them was to program and set up a wrist sensor. This should be able to be used for field tests. The aim was to find out in which measuring range the forces occur during a fall. Due to technical limitations, however, this could not be determined exactly. It was possible to say that the measuring range is above the 16 g (with a hard underlying surface), but the exact span in which the forces lie cannot be determined. However, the trigger also had to be adjusted. It would be necessary to analyse under which conditions the trigger could otherwise be released, e.g. when clapping or similar movements. This would require measurements during snowboarding itself with the accompanying monitoring of when and by what the sensor was triggered. The originally selected trigger could not be triggered by clapping or similar movements in preliminary tests, but this would have to be investigated in more detail in order to obtain the optimum trigger value. A neural network could possibly help to distinguish between falling and clapping or similar. In general, a more precise statement about the use

TABLE VIII
MEAN VALUES AND STANDARD DEVIATION FOR THE AUSTRIAN FEMALE FROM A RELATIVE DROP HEIGHT OF 30 CM.

Body Size:		**Austrian Female**	
Relative fall height:		**30 cm**	
Protector:	**None**	**Inline**	**Snowboard**
Normal force (N):	2632,54 ± 56,13	2388,08 ± 55,31	2133,76 ± 61,64
Parallel force (N):	863,95 ± 20,02	625,69 ± 15,39	592,86 ± 28,06
Resulting force (N):	2770,81 ± 52,90	2468,80 ± 52,48	2214,67 ± 64,74
Angle θ (°):	18,18 ± 0,57	14,69 ± 0,54	15,53 ± 0,52
Jerk x-axis:	122598,5 ± 23975,6	95260,0 ± 13897,1	61375,6 ± 4021,3
Jerk z-axis:	236072,5 ± 32976,8	162378,1 ± 23118,6	166478,4 ± 22238,4

of the trigger can only be made when data from field tests are available.

In general, a different sensor must be used for field tests. When choosing a sensor, it is important to ensure that it has a high frequency count. A more detailed analysis of the data and the graphs showed that the frequency used for the acceleration data is not sufficient to determine the peaks of the data accurately. Therefore, the data obtained are only approximate values and do not serve as precise indications of force effects or the occurring jerk. Likewise, a sensor should be selected that can measure very high g forces. When selecting the components, it is also important to bear in mind that they will be used in a cold environment. Low temperatures should have a low to no influence on the results. In addition, the attachment to the wrist or glove must be done in such a way that it is not damaged by the fall. It should also be attached as rigidly as possible to the body.

Another goal was the development of a fall simulator. The aim was to use the most realistic size ratios possible. Setting up and adjusting the apparatus was not a major challenge. The biggest problems were the joints. The same alignment is a major criterion here. When using flexible wrists, there was also the problem that if you wanted to use a certain wrist angle, this might already be slightly changed by the wrist protectors due to their pre-tensioning. This problem does not exist when using fixed joints. However, the bending of the wrist cannot be determined in this way. The question is whether the user adopts a different wrist angle when using different protectors. This is also important because when snowboarding, you usually don't fall down on a straight underlying surface but operate on a slope where, depending on the steepness of the slope, you hit the ground at a different angle.

In general, this work showed which factors have a decisive influence on the forces obtained like wrist angle or the detection of the parallel force. However, these factors are not taken into account in the drop test of the ISO 14120 as described in the work by [12]. Similar tests were also used in the work of [17], which are therefore also considered less relevant. The method of [13] is also not considered useful. This is because the forces are not measured in the same way as they would be in a real fall situation. It is important not to measure the protectors in the way they are most efficient, but in the way they are used in real situations. This is an important aspect that must be taken into account when creating the test standard. In the opinion of the author, the fall simulator presented in this paper is a better alternative. It needs some fine tuning to reduce the measurement inaccuracies, but the basic structure gives a more realistic fall simulation than the previously mentioned works.

In total, at least 660 drop tests were conducted over the three test runs. The respective protectors were each subjected to more than 200 drop tests. Due to the normal distribution of the forces, there was no evidence of any significant deterioration of their absorption due to material fatigue. Neither the hand nor the protectors were ever replaced. It should also be noted that protectors from the lower price range were used.

When using both protectors, a significant reduction in parallel forces was observed. Only the data of the fall height from 30 cm was evaluated with the size of the European Human. In the case of the normal forces, both also caused a significant change, but the snowboard protector contributed to a reduction in the force and the inline protector to an increase. The round shape of the hard shell of the inline protector leads to the assumption that the closer to the edge the force occurs, the less damping is applied. With the snowboard protector, the surface area of the protective foam decreases in the direction of the fingers. This presumably leads to the lower protective performance at a different angle of fall and the resulting change in the impact surface. On the other hand, it must be noted that from a certain angle, the fingers hit the force plate first. These then also serve as dampers and reduce the maximum force that occurs. The influence of the fingers on real falls could therefore also be investigated more closely. All in all, the angle of impact is considered an important factor in falls. A change in the angle can quickly lead to more punctual loads, which have a greater impact on the wrist. This should therefore be an important criterion when testing this protector. The tests must be carried out from different wrist angles to ensure that the protectors also provide better protection at unfavourable angles.

V. CONCLUSION

The aim of developing a fall simulator with which you can simulate falls such as tipping over forward as realistically as possible was largely developed according to the requirements. However, the positioning of the wrist still leaves open questions that need to be clarified. In general, it has been found that the angle of impact of the wrist has a great influence on the forces received. Protectors therefore provide different protection for smaller deviations in the angle of impact. The angle required for such a significant change has not yet been investigated. This must also be determined individually for each protector.

Using the wrist sensor showed that the jerk is suitable as a trigger, but not whether this is the optimal solution. The range of values could not be determined with sufficient accuracy because the frequency was too low. Therefore, the values obtained only serve as a rough guide. Due to the small measurement range of only 16 g, it was also not possible to determine how many g forces act on an impact on a hard underlying surface.

Using the force plate, relevant correlations between fall height and shoulder height could be determined. Using different shoulder heights in combination with the protectors has identified that the hand has a different angle to the ground while the impact. This has a significant influence on the normal force that occurs. The influence is greater than that of the lower angular velocity.

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