TRACKING OF THE HAND "PRESSURE POINT" ON THE GRIP OF A RECURVE BOW: A WEARABLE SOLUTION

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The purpose of this study was to design and prototype a non-invasive wearable solution suitable for measuring speeds, accelerations and orientation of the hand-grip as well as the pressures between the hand and the grip of a recurve bow. Therefore, a device has been created that properly blends two technologies: an Inertial Measurement Unit (IMU) and a Force-Sensitive-Resistor (FSR) membrane. A preliminary evaluation of the device performance was conducted in collaboration with the Olympic athlete Mauro Nespoli. The obtained results demonstrate the potential of the proposed system, as well as highlight a number of interesting information from a biomechanical point of view, closely related to the shooting technique.

KEYWORDS: equipment, wearable technology, motor control.

INTRODUCTION: Is it possible to characterize, strictly from a biomechanical point of view, the pressure point of the hand on the bow's grip? If so, what is the least invasive experimental setup that allows to carry out such an analysis? And again: how much does a correct and repetitive positioning of the hand and the relative pressure point can affect the athlete's performance? The hand pressure point on the grip of the bow is a *"fundamental of the shooting sequence"*. Among others, Martin P. et al. (1992), Cockrell R. A. (2004), Lee K. (2012), Wise L. (2014), Reilly P. (2017), Lee K. et al. (2018) provided a number of studies, theoretical models and technical notes in this regard. However, there is no knowledge about on-the-field applications. Moreover, the positioning of the hand and the pressure point exerted on the grip are difficult to interpret, as they cannot be observed directly by the technician. They are perceptive aspects of the archer. Verbal feedback therefore represents the only way to modify and improve his technique, in relation to the reaction of the bow after the release and the impact of the arrows on the target. The goal of this project was to provide a non-invasive wearable device capable to measure the speed, acceleration, orientation and pressure point of the hand on the bow's grip during the gesture itself, without altering it in any way. Providing a theoretical and practical tool with which to evaluate the athlete's technique during the whole shooting gesture can be useful to trainers and athletes themselves for two main reasons: 1) improvement of shooting technique based on objective data and quantitative performance assessment; 2) evaluation of a "correct" handle that favours a comfortable and natural position, thus reducing possible muscle contractions and consequent injuries.

METHODS: The proposed equipment (Figure 1) has a form factor of 31 mm x 29 mm. The core unit includes a 6 Degrees Of Freedom (DOFs) inertial sensors and a 3D magnetometer. It manages the connection of 2 Time-Of-Flight (TOF) peripherals, not used in this study, as well as of a 16-channels FSR pressure sensors by means of a ZIF connector (i.e., 16 lines plus 1 or 2 ground pins). An ultra-low power microcontroller produced by ST Microelectronics was integrated on-board to deal with data collection and processing tasks. The device provides USB and Bluetooth Low Energy connectivity, and includes a 64 MB NOR flash memory for log capability.
The pressure sensor is a custom product based on the FSR technology. It is a sandwich assembly made with two polyester layers, one for deposition of silver traces and one for deposition of resistive pads. The pressure sensor behaves as a passive component.

[1] https://www.221e.com/
[2] https://www.coni.it/en/national-sports-federations/italian-archery-federation-fitarco.html

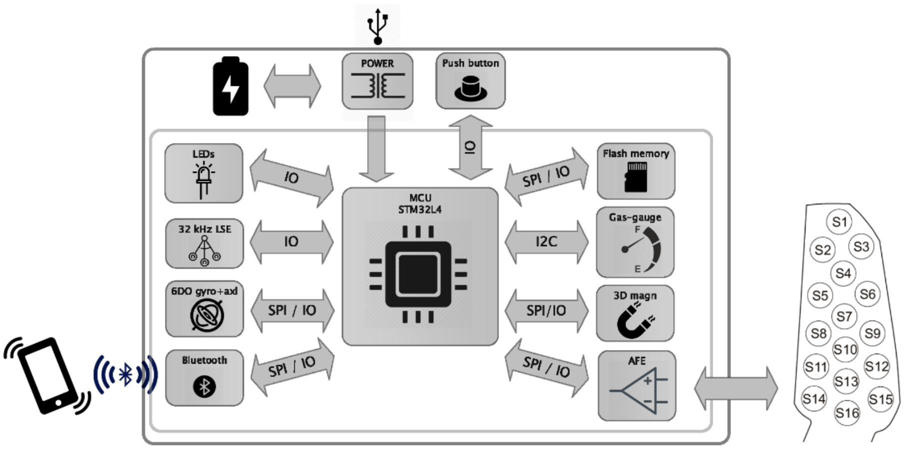

Figure 1: Conceptual representation of the equipment building blocks.

The whole equipment was mounted on the hand, as well as on the grip, of the archer, as depicted in Figure 3 and Figure 2, respectively.

Figure 3: SETUP A - Experimental setup with IMU positioned on the back of the hand.

Figure 2: SETUP B - Experimental setup with IMU positioned on the riser, just below the grip.

In order to assess the proposed design and perform a preliminary characterization of the hand pressure point on the grip of the bow, 3 experimental sessions, with the two aforementioned setups, were organized as follows: 1) ***VOGHERA #1***, training session (SETUP A, Figure 3) held in Voghera, Pavia, Italy, 29.06.2019 @A.S.D. Arcieri D.L.F. Voghera[3], 72 arrows, 70 mt; 2) ***PADOVA***, interregional competition (SETUP A, Figure 3) held in Padova, Italy, 04.08.2019 @A.S.D. Arcieri RIO, Ponte S. Nicolò[4]. Competition code: R1906055[5], 72 arrows, 70 mt; 3) ***VOGHERA #2***, training session (SETUP B, Figure 2) held in Voghera, Pavia, Italy, 09.09.2019 @A.S.D. Arcieri D.L.F. Voghera, 72 arrows, 70 mt. The subject involved in the study was the Olympic athlete Mauro Nespoli[6]. During the period of the acquisitions, he did not complain of injuries and / or disorders of the musculoskeletal system that could in any way affect his performance. The subject was previously informed about privacy, non-invasiveness of the tests and equipment, in accordance with current national and international regulations.
The inertial and pressure data were saved as plain text and processed into Matlab[7] environment. Each trial was temporally windowed based on the first positive acceleration peak (i.e., greater than 5 g) detected along the x-axis, during the shooting phase. The threshold was experimentally chosen. Then, the same operation was automated, implementing an algorithm capable to identify the 4 typical shooting phases using the inertial measurements. In particular:

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[3] http://www.dlfvoghera.it/arcieri.html
[4] http://www.asdarcieririo.it/
[5] http://www.fitarco-italia.org/gare/classificaDB.php?Codice=R1906055
[6] https://worldarchery.org/athlete/5796/mauro-nespoli
[7] MATLAB R2013a, The MathWorks, Inc., Natick, Massachusetts, United States.

1) *Grip* phase during which the archer holds the bow; 2) *Raising* phase during which the archer raises the bow, pointing it at the target and begins the phase of pulling the rope; 3) *Traction / Aim*, closure of the traction phase and alignment of the arc to the target; 4) *Release* of the rope and consequent release of the arrow, shooting.
After a preliminary verification of the consistency of the acquired data and a qualitative analysis, the attention was paid to the study of the distributions of the loads measured by the pressure sensors and the estimate of the relative Center of Pressure (COP). Finally, the score of each arrow was correlated to the corresponding pressure profiles and COP. In this regard, standard scores were assigned, as per regulation, to each arrow. The COP calculation was implemented on a matrix basis. Considering the positioning of the pressure sensors on the plane (Figure 1). The row and column index that identify the position of the COP were then calculated as average of the pressure values recorded in each square weighed by the index of the square itself.

RESULTS: With respect to the aforementioned analysis, over the 216 arrows recorded in the three sessions, the obtained results can be summarized as follows. For angular velocities and accelerations, whether they are recorded on the archer's hand rather than directly on the grip, they vary through the different acquisitions in relation to the particular setup of the bow. The most evident aspect regards the peak acceleration values recorded during the VOGHERA #2 acquisition, which are doubled compared to VOGHERA #1 and PADOVA, together with halved angular velocities. These findings seem to be explainable by the greater weight / inertia of the system. During the experiments there was an increase of 312 grams on the central stabilizer and 156 grams on the lateral stabilizers, together with a lowering of the center of gravity of the overall system.

Table 1: Statistical descriptors of recorded shoot performances in terms of angular velocity and linear accelerations.

	Gyroscope [dps]	*Accelerometer [g]*
Voghera #1	435.1 ± 70.1	6.893 ± 1.835
Padova	771.2 ± 237.5	5.188 ± 1.130
Voghera #2	354 ± 115.7	12.12 ± 2.65

In terms of pressures exerted by the hand on the grip, the following aspects emerge: 1) The position of the pressure point, during the raising and traction phases, is constant through all the acquisitions that have been made and stands around the s7 pad. 2) It is possible to distinguish at least 4 different ways (Figure 4) of reaching the same pressure point, as trajectories traveled by the COP within the matrix that identifies the measurement points of the membrane.

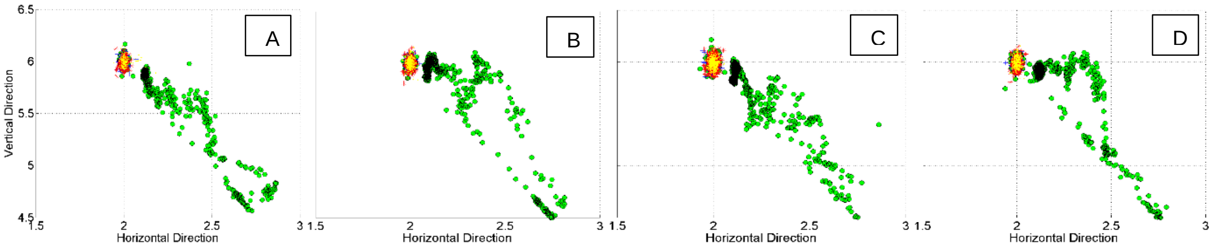

Figure 4: Trajectories with which the athlete get the same pressure point. x, y axes represents the column and raw index of the reference matrix. The color of the points change based on the shoot phase. In particular, the red and yellow points highlights the last part of aiming and shooting action, respectively.

3) The intensity of the pressures detected during the acquisition of PADOVA (performed during a competition), is 10-15% higher than that recorded during the training sessions of both VOGHERA #1 and VOGHERA #2. The higher intensity recorded during the competition (PADOVA) cannot be attributed to a different experimental protocol rather than to a different positioning of the membrane. The two acquisitions held in Voghera exclude such a possibility

having used two different setups: membrane and system fixed on the hand of the archer (VOGHERA #1) against equipment fixed on the riser and grip of the bow (VOGHERA #2).

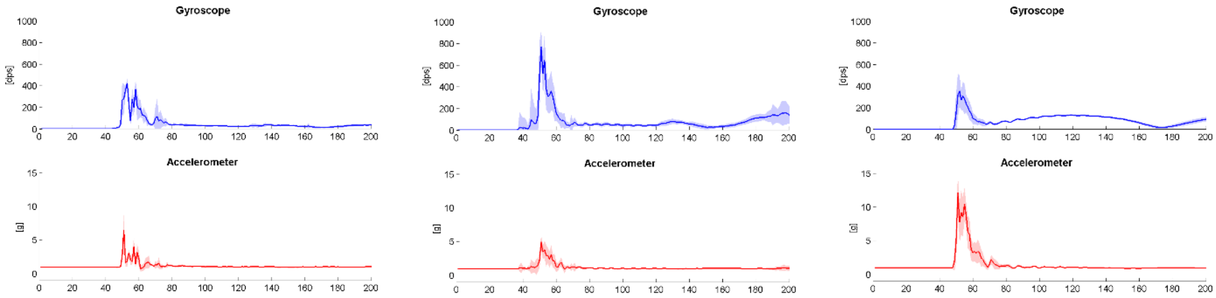

Figure 5: Mean values ± one standard deviation, angular velocities (BLUE) and linear accelerations (RED) over a 2 seconds time window around the shoot event.

4) To a greater pressure exerted on the grip seems to correspond also a general greater variability of the inertial data. 5) The correlation between the COP, the types of trajectory and the score obtained by the archer. The element that stands out most is the timing that characterizes the strokes with the best scores compared to those with lower scores. Times clearly higher or lower than 4 seconds lead to compensation actions, irregularities in the gesture and in general lower scores. On the other hand, timings in the range of 4-4.5 seconds (i.e., understood as the time that the total execution of the athletic gesture) have a positive impact on higher scores.

DISCUSSION: This study confirm how the hand "pressure point" on the grip of a recurve bow plays a central role in relation to the athlete's performance. This is in line with what has already been widely discussed in the literature. However, completely new information emerges: there may be different ways in which *"to reach"* a suitable pressure point. Such a knowledge opens up a different perspective compared to what has been done so far: evaluate how different actions on the grip, with the same final positioning of the pressure point, affect the performance in terms of points to the target. Is it possible to intervene at the shooting technique level rather than bow configuration to compensate, correct or modify the way the archer develops a certain pressure point? Aware that the work carried out so far has some limitations, including: lack of a direct correlation between hand and grip orientation, as well as with other types of information such as upper limb electromyography and kinematics; it is also worth noting that such limits constitute the future directions in which to continue the study and improvement of the proposed equipment.

CONCLUSION: The obtained results and the proposed measuring instrument lay solid foundations aimed at encouraging the approach to archery in a scientific way. Such a tool allows to objectively evaluate a fundamental aspect of the shooting sequence, without altering in any way the gesture of the athlete. Moreover, it also lays the basis for the development of other platforms of this type, that can be used also in other sports, with the aim of stimulating the study of movement biomechanics in an ever more in-depth way, as well as improving athletic gesture techniques, reducing possible injuries.

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