E-textile touch button placement with a help–request function for smart sportswear

I.N. Tyurin[1*], *A.G.* Kuzmin[1], *L.V.* Komisaruk[1], and *S.Sh.* Tashpulatov[2]

[1]Kosygin University, Sadovnicheskaya str. 33, 115035 Moscow, Russia
[2]Tashkent Instite of Apparel and Textile Industry, 5 Shoxdjaxon str., Tashkent, Uzbekistan

Abstract. Due to the high risk of injury to an athlete during sports training, the diagnostic and monitoring functions of sportswear are among the most potentially demanded. The article is devoted to the investigation of optimal topographic areas for a textile touch button placement with a help–request function. A touch button is part of a flexible printed circuit board that is integrated into the structure of highly functional, tight-fitting sportswear. It was determined that the button should be placed so that an athlete takes the minimum amount of time to move and press the button. In this paper, the minimum values of the modulus of a vector of the athlete's hand movement when pressing a touch button after a sudden deterioration of the athlete's health were determined. The study was carried out by measuring the trajectory lengths in dynamic postures that constitute the phase schemes of falls on the example of athletes performing plyometric jumping, walking, and running, as well as in static positions.

1 Introduction

Due to the high risk of injury to an athlete during sports training, the diagnostic and monitoring functions of sportswear are among the most potentially demanded. It is worth noting that the most vulnerable groups are the elderly [1] and people with chronic diseases, mainly cardiovascular, locomotor apparatus [2, 3]. A particularly high risk of injury, as well as a sharp deterioration in physiological state, is associated with athletes participating in extreme sports [4]: mountaineering, powerlifting, gymnastics, extreme cycling (BMX, mountain biking, track cycling), equestrian sports, skiing and roller skiing [5], kayaking and canoeing, CrossFit (high-intensity functional training/functional multisport competition).

There are many more extreme sports, or more precisely, sports that involve possible extreme situations, but it is the above that an athlete participates in individually and/or outdoors with other athletes, distant by significant distances (for example, participation in a cross-country race on a mountain bike). The CrossFit workout (functional training) listed above requires more attention because of the simultaneous confluence of 2 circumstances. According to a report published in 2018 by the American network CNBC [6], the CrossFit workout is the most popular and fastest growing sport in the world, with more than 4 million athletes training (about 10 million according to CrossFit, Inc.) and more than 13,000 gyms

* Corresponding author: iniruyt1409@gmail.com

in 120 countries [7]. However, this training is one of the most traumatic. One of the main factors that increase the injury risk is high-intensity training: functional training consists of constantly changing exercises from different sports with extremely short rest periods. Some training programs also include exercises from sports that cause the most injuries: weightlifting, plyometrics, kettlebell lifting, strongman training, and some others [8, 9]. In addition, the high-intensity only increases the risk of injury associated with these exercises.

At the same time, sports training, especially high-intensity functional training, involves a series of complex and highly variable biomechanical movements that make it difficult to post-process the obtained flow of three-dimensional coordinates of human body position. Meanwhile, it is important to note that the biomechanical positions of a fall may be similar to those of an athlete performing a particular exercise. The solution to these problems requires a biomechanical analysis of the athlete's movements before and after their fall, a comparative analysis with all phase schemes of motions in a given exercise, as well as the introduction of additional sensory elements in the flexible PCB to monitor and diagnose the athlete's physiological state (heart rate, muscular activity, etc.). Therefore, when designing tight-fitting sportswear, it is suggested that the body-state tracking function be assigned to the athletes themselves rather than to the user software, while the flexible PCB notifies the user of sudden health deterioration and the need for medical assistance.

As mentioned above, the capabilities of highly functional sportswear with integrated flexible circuit boards or e-textile elements can be activated either by the system itself (the software as part of the flexible circuit boards) or by the user. For example, in the papers by Baskan H. et al, Atakan et al [10, 11], the system can measure the level of physical activity and performance, detect the user's fall and transmit the data obtained via Bluetooth.

The fall detection system [12] based on inertial sensors is described in the papers by Jian He et al. The system can automatically detect a fall event and alert a third party for immediate assistance to reduce injuries caused by falls.

A wearable fall detection system consisting of a deformable triboelectric generator made of conductive nylon and a lithium-ion battery combined with integrated sensors, controllers, and wireless devices was demonstrated in the paper by Sungmook Jung et al [13]. The electrical energy produced by the triboelectric generator as a body moves continuously recharges the stretchable battery and increases its operating hours. A built-in power supply drives a 3-axis accelerometer and associated electronics that track body movement and transmit data wirelessly. In the event of an unexpected fall, the user software detects a fall alarm and immediately sends an emergency alert to an external mobile device.

In conclusion, there are high quality developments in the area of fall detection systems with a help–request function. At the same time, most of the developments are in the field of wearable electronics, that is, they are separate devices in relation to clothing. In the area of smart clothing design, including highly functional sportswear, developments are presented at the prototype level and activated by user software as part of an integrated system.

An important issue when designing tight-fitting sports apparel with a help–request function is the placement of a touch button. The process of deterioration of the athlete's condition is fast and lasts 1–10 seconds. An athlete often experiences discomfort and pain of varying intensity in muscles, ligaments, joints, and the cardiovascular system that limits and sometimes paralyzes any motor activity [14, 15]. So the placement of a touch button in the clothing should meet the condition: the work (A, J) done by a person while moving to a touch button and in the process of pressing it should be minimal.

$$A = A_{min} \tag{1}$$

It requires the principle of minimum force and displacement:

$$\mathrm{Amin} = \int \vec{F}_{min}\, d\vec{S}_{min} \quad (2)$$

In our study, the subject of which are athletes of different training levels, engaged in CrossFit workouts strength is demonstrated in the biomechanical movements of body parts, where the main function is performed by a hand, auxiliary — a torso, head. In order to minimize the force when pressing the button, it is necessary to study the muscular activity of the human body while pressing the button and select the most optimal ones.

It is necessary to study and select the shortest trajectories of the human hand movement to a touch button while an athlete falls during physical activity to minimize the modulus of a displacement vector.

In this paper, we decided to focus on determining the minimum trajectory lengths of the human hand movement to minimize the modulus of a displacement vector. Thus, the aim of this study is to determine the minimum values of the modulus of a vector of the athlete's hand movement when pressing a touch button after a sudden deterioration of the athlete's health and to establish the optimal topographic areas of the touch button placement on tight-fitting sportswear.

First of all, it is necessary to classify the types of falls during sports training (Fig. 1). We have observed 4 types of falls: in conditions of static state, in conditions of dynamic states when performing strength exercises, plyometric jumps or aerobic load.

The athlete's static state can be observed during the rest period between exercises/repetitions, the pre-training warm-up. The complexity of analyzing a “static” fall is related to the need to determine the specific causes of a sudden deterioration in the physical state. They can occur both as a result of current physical activity or as an incidental occurrence of previous health problems [2]. Falls that happen in dynamic states differ both in the phase schemes of movements and in the causes that lead to them. The reasons for the sudden deterioration of the physical condition when performing strength exercises are the increase in pressure, cardiovascular diseases, injuries to the limbs caused by falling sports equipment on the athlete's body (barbells, bars, weight plates, dumbbells).

Based on the analysis of athletes performing plyometric jumps as part of high-intensity functional training, we found that a fall is mainly caused by the inability to complete the penultimate stage of the exercise, which is standing on the supporting surface (wooden box), due to the great height of this equipment.

Aerobic exercise, such as walking, running, swimming, rowing, and bicycling/stationary cycling, performed at low intensity for 2 to 20 minutes, can cause [2] sudden cardiovascular deterioration, increased blood pressure, dehydration, and sunstroke. Our analysis of athletes performing aerobic exercise indoors shows that another cause of falls is excessive speed on treadmills.

Next, based on the analysis of training videos and in-person training observations of athletes of different training levels, phase schemes of the 4 types of falls were developed. The case of injury caused by falling equipment on the athlete's body is excluded in the following stages because the athlete's fall at this point is very rare (12%) and the phase schemes of action after the injury are extremely different.

Figure 1 shows the phase scheme of a fall when performing a plyometric jump. The scheme consists of 7 phases, the fall itself is described by the last 3 phases (5–7). The fall begins when the athlete is unable to stand steadily on a supporting surface (wooden box – equipment) and begins to fall backward on the pelvis or back + pelvis.

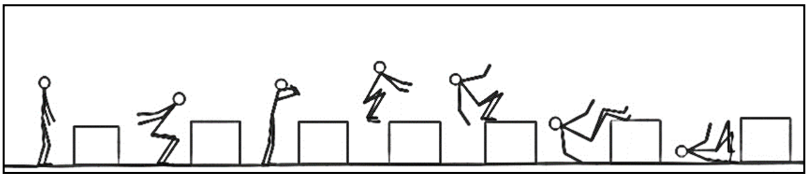

Fig. 1. Phase scheme of the fall during a plyometric jump

Figure 2 shows the phase scheme of the fall during treadmill running. The fall occurs in the 4th phase when the athlete is no longer able to alternate the legs, push out and perform the flight phase, the legs slide backward and the body follows the legs. Most often, the athlete attempts to grab the treadmill handrail, to press the emergency button. In rare cases, the athlete can stand on the fixed side panels. A typical feature of such a fall is the athlete's tendency to roll over onto their back after falling on the treadmill belt. The phase cycle shown in Fig. 2 is similar in the case of classical running with an unattached support surface. The only distinguishing feature is the presence of the treadmill handrails and the athlete's tendency to hold on to them at the first moment of the fall.

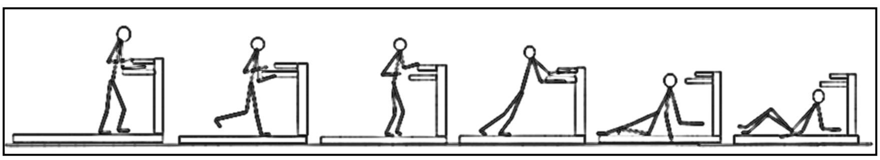

Fig. 2. Phase scheme of the fall on a treadmill

The phase schemes of the fall shown in Fig. 3 are presented in 2 variants. The upper phase scheme is a priority in case of emergency deterioration caused by abnormal functioning of the cardiovascular system: hypertension (high blood pressure), coronary heart disease (heart attack), brain circulation disorders (stroke), a sharp deterioration of the gastrointestinal tract, a sudden deterioration of the functioning of internal organs (liver, kidneys). In this situation, the fall process begins by bending the knee joint, because it is difficult for an athlete to be in a standing position, so he/she begins to squat while the center of mass is shifted forward.

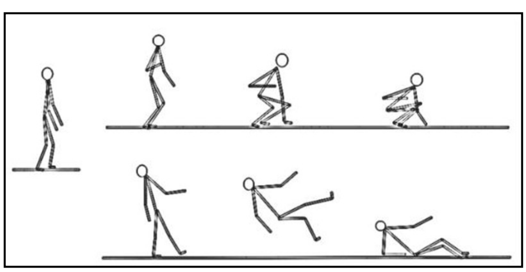

Fig. 3. Phase schemes of the fall in a static state while standing, walking, or performing strength exercises (2 variants)

In the second case (lower phase scheme), the athlete's center of mass is shifted backward, then in the "flight" phase, the lower limbs are thrown forward and slightly upward while the dominant hand stretches down to reach the supporting surface, and the other hand is thrown slightly forward while the body is tilted in the direction of the supporting hand. In the final phase of the fall, the athlete lands on the supporting surface. The forearm and gluteal muscles are the contact surfaces in this case.

To sum up, it should be pointed out that the common thing in falling backward in different conditions is body twisting, reaching the supporting surface with the dominant hand, and lifting the other hand slightly upward.

2 Materials and methods

The first stage of the research was the creation of a list of anthropometric points to measure the trajectory lengths of hand movements, the result of which is the pressing of a “smart” button.

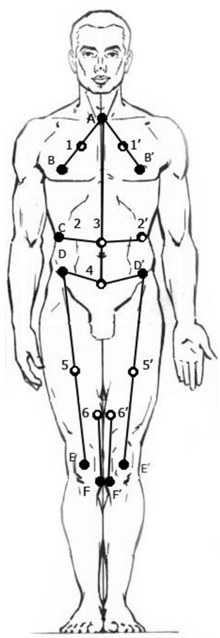

Fig. 4. List of anthropometric points

When conducting researches, we used 6 basic anthropometric points to calculate additional required anthropometric points 1/1' to 6/6': A — suprasternale; B, B' — thelion; C — zonalelaterale; D, D' — ilisopinale; E, E' — patellare; F, F' — tibialemediale. At the same time, we used some of the above set of points for measurements: B/B', D/D', F/F'. Points 1 to 6 were calculated as follows: point 1 is at the midpoint of the segment AB; point 2 is at a distance of 0.1OT, where OT is the waist circumference; point 3 is at the intersection point of the vertical line descending from point A and the waist circumference line; point 4 is at the intersection point of the curve DD' and the vertical line descending from point A; point 5 is at the midpoint of the segment DE; point 6 is at a distance of 0.45 DIL, where DIL is the inner leg length from the tibiamediale to the perineum. Points 1'-6' are symmetrical.

The additional anthropometric points were selected for the following reason: point 1/1' was chosen because (unlike point B) it is not necessary to move the elbow to the side to touch these points with the palm of the hand, which can be complicated in an emergency situation. Points 3 and 4 were picked for comparison with the selected points 2/2' and D/D', points 5 and 6' are convenient for touching with the right hand, 5' and 6 for touching with the left hand.

A list of measured trajectories of movements with the right hand was made: MB', M1', M3, M2', M4, MD', M5, M5', M6' and with the left hand: M'B, M'1, M'3, M'2, M'4, M'D, M'5, M'5', M'6. It should be noted that in most cases the projected trajectory is not straight, but curved (Fig. 5). The only exception is the hand movement perpendicular to the body, where the flexible PCB with a touch alarm button is located. An example of this type of movement is touching the front of the thigh with the palm of the hand (trajectories M5 and M'5').

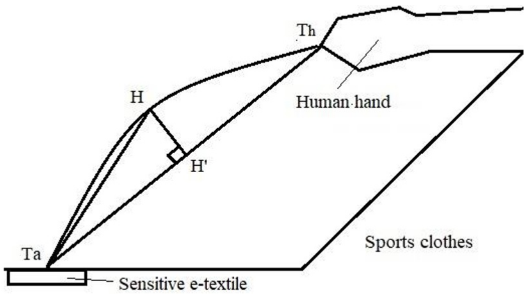

Fig. 5. Hand trajectory to press a touch button

So we used the Huygens formula to calculate the curvilinear trajectories of the hand movements:

$$\widetilde{T_h T_a} \approx 2T_a H + \frac{1}{3}(2T_a H - T_h T_a), \quad (1)$$

where $\widetilde{T_h T_a}$ — arc length (curvilinear trajectory), $T_a H$ — chord length, $T_h T_a$ — chord length — arc projections $\widetilde{T_h T_a}$.

Since measuring a chord $T_a H$ is technically difficult, we express the chord by the HH' perpendicular to the chord $T_h T_a$. As a result , we get:

$$\widetilde{T_h T_a} \approx \frac{4}{3}\sqrt{4HH'^2 + T_h T_a{}^2} - \frac{1}{3}T_h T_a. \quad (2)$$

Thus, we measured the height of the projection trajectory and its length in a straight line to find the lengths of the curvilinear trajectories. Then, using formula (2), we found the lengths of the curvilinear trajectories of the hand movements for pressing a textile touch alarm button located on a flexible PCB integrated into the athlete's clothing.

The study subjects were 2 men and 2 women of different somatotypes, aged 24–61 years. Table 1 shows the parameters of the subjects studied.

Table 1. Parameters of male subjects (N = 2)

Parameter	Height	Chest circumference	Waist circumference	Hips	AB	2-2'	DD'	DE	6F
Average	176.9	89.5	85.4	96.2	17.1	29.5	29.9	51.8	17.1
Scatter	171.3-182.4	82.2-96,8	78.3-92.5	91.8-100.5	16.7-17.5	28.9-30.1	29.1-30.6	50.2-53.4	16.3-17.9

Table 2. Parameters of female subjects (N = 2)

Parameter	Height	Chest circumference	Waist circumference	Hips	AB	2-2’	DD’	DE	6F
Average	166.7	103.4	93.9	104.2	16.5	30.6	30.9	48.3	15.9
Scatter	164.5-168.8	94.5-112.3	82.3-105.4	97.8-110.5	16.3-16.6	29.7-31.5	30.1-31.7	47.2-49.4	15.6-16.1

Dimensional features and curvilinear trajectory lengths were captured and measured using the 360 Kinect 3D scanner and Ansys SCDM 19.1 software (Fig. 6). The data were statistically processed and the results of which allow us to conclude the accuracy of the results.

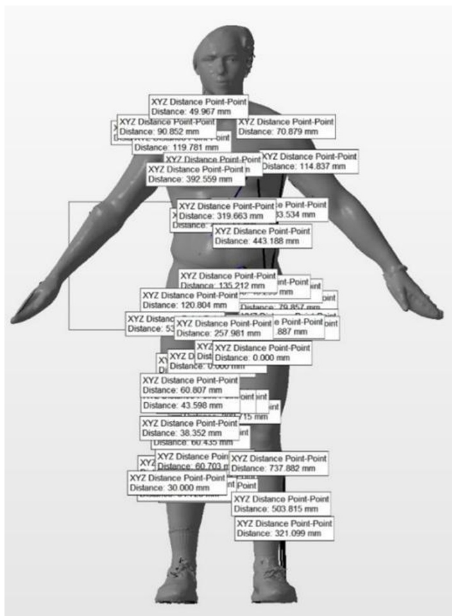

Fig. 6. The process of measuring the lengths of trajectories and dimensional features on a 3D scan of a human figure

3 Results and discussion

As a matter of practice, the friction of flat samples is ascertained with the usage of Table 3 shows the sample average values of the trajectory lengths of the touch notification panel on the flexible PCB in sportswear.

Table 3. Sample average values of the trajectory lengths of the touch notification panel on the flexible PCB in sportswear.

Drop load type	Phase	Side	**Lengths of curved paths**							
			MB’/ M’B	M1’/ M’1	M3/ M’3	M2’/ M’2	M4/ M’4	MD’/ M’D	M5/ M’5	M6’ / M’6
Plyometric jump	5	Right	81.2	79.0	**64.1**	73.2	**65.2**	77.1	69.3	80.1
		Left	70.9	68.0	67.8	80.5	67.2	78.7	**60.1**	81.3
	6	Right	74.0	78.5	67.3	80.6	85	71.5	74.3	88.5
		Left	70.3	69.6	67.8	79.7	63.4	77.3	68.3	**66.8**
	7	Right	68.2	71.0	75.4	85.2	93.2	80.2	101.5	117.7

		Left	**32.3**	**39.5**	61.7	**50.0**	61.2	76.3	**54.2**	73.1
Aerobic exercise	4	Right/ left	64.2	**63.2**	72.3	73.4	77.2	76.8	85.8	100.4
	5	Right/ left	**67.9**	68.2	76.2	77.4	81	79.2	70.0	74.5
	6	Right/ left	**68.1**	71.3	91.4	78.2	74.3	94.6	84.4	101.9
Static (power) loads	2	Right	**25.3**	**23.8**	**24.3**	31.7	33.2	40.4	36.3	58.4
		Left	64.1	64.1	48.5	56.2	42.4	57.5	26.4	39.7
	3	Right	**14.6**	**13.4**	**17.2**	**21.1**	32.1	**21.3**	30.8	41.6
		Left	63.4	64.9	54.6	66.2	50.5	62.7	40.4	**25.0**
	4	Right	**18.6**	**16.4**	**17.2**	**23.8**	**25.5**	31.4	**22.1**	38.4
		Left	62.7	63.1	56.0	66.4	55.7	67.2	**39.0**	55.7
Walking	2	Right	62.5	63.3	64.3	52.3	47.3	59.9	**33.5**	60.2
		Left	65.1	67.7	64.7	67.3	63.4	76.4	62.6	80.3
	3	Right	68.3	66.5	**55.2**	69.9	**56.0**	70.5	61.3	80.4
		Left	70.9	68.4	60.1	76.2	61.9	76.6	**44.7**	80.7
	4	Right	57.0	56.3	**43.4**	58.6	53.6	66.2	63.4	74.6
		Left	67.2	68.5	57.6	71.8	56.8	72.4	**42.3**	60.3

According to the data analysis obtained, it was found that the shortest trajectories were received during the movement of the dominant hand. It should be emphasized that all subjects were right-handed, so the right hand predominates in our study.

The trajectories MB', M1', and M3 obtained as a result of a fall under static (force) load are absolutely minimal. When falling during a plyometric jump, the most optimal trajectories are M'B, M'1, M'2, and M'5. When falling during aerobic exercises, only the symmetrical trajectories MB'/ M'B are the most optimal. In the case of a simulated fall while walking, the trajectories M3 and M'5 for the right and left hand, respectively, have the minimum length.

Thus, a list of trajectories is created, as shown visually in Fig. 7.

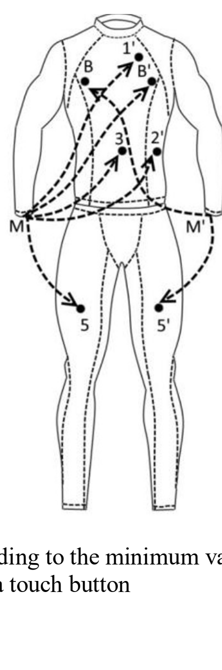

Fig. 7. Curvilinear trajectories corresponding to the minimum values of the modulus of a vector of the athlete's hand movement while pressing a touch button

Figure 8 shows the prototypes developed by the authors of a highly functional, tight-fitting apparel using the example of a rashguard with an embedded flexible PCB. The rashguard is designed based on previous research [16-18]. First, when the athlete experiences a sudden deterioration in health, he/she presses a textile touch button (sensitive e-textile), which reduces the resistance of the sensory textile (e-textile). The process of rapidly decreasing the resistance of the conductive fabric is recorded by a microcontroller and stored in RAM. A microcontroller with a Bluetooth wireless communication module then sends a signal about an emergency situation and the need for help. Initially, the signal is transmitted to the application on the user's mobile device, and then the application activates the conditional operator (applet) and sends a command to send a signal for help. A signal of an emergency situation and for help can be received by a third party (the athlete's family and friends) in several ways: SMS, e-mail, or phone call.

Fig. 8. Prototypes of a tight-fitting rashguard with embedded PCB

4 Conclusion

The data obtained as a result of this study are the minimum values of the modules of vectors of the athlete's hand movement while pressing a touch button after a sudden deterioration of the athlete's health and can be used to design highly functional, tight-fitting clothing.

The next step is to determine the minimum values of the moduli of force required to press a touch button. It is recommended to use a muscle activity sensor for the study.

It should also be noted that the study is aimed at finding the optimal location of a textile touch button, while the location of the PCB is not regulated. Meanwhile, the PCB occupies a surface area of about 10 cm^2 and contains rigid components in its structure. For this reason, the parts of the body that are subject to bending and twisting should be studied more closely for comfortable wearing conditions.

References

1. D. Baumgartner, Mécanismes de lésion et limites de tolérance au choc de la tête humaine—Reconstruction numérique et expérimentale de traumatismescrâniens. (Ph.D. dissertation, Université Louis Pasteur Strasbourg I, France, 2001)
2. P.T. Williams, Med. Sci. Sports Exerc. **33(5),** 754–761 (2001)

3. P.T. Williams, Arch Intern Med. **157(2),** 191–198 (1997)
4. B.P. Chinn, D. Doyle, D. Otte, E. Schuller, *Motorcyclists head injury: mechanisms identified from accident reconstruction and helmet damage replication.* Proceedings of the IRCOBI Conference, Barcelona, Spain, September, pp 53–71 (1999)
5. M. Jonsson Kårström, et.al., Rifle carriage affects gear distribution during on- snow skiing in female and male biathletes (2023). Doi:10.1080/02640414.2023.2189796
6. N. Perić, The analysis of the market position and marketing potentials of crossfit **9,** 69-77 (2019) doi:10.5937/snp1902069P
7. E. Gianzina, O. Gianzina - Kassotaki, Sport Sciences for Health **15**, 21-33 (2019). Doi: 10.1007/s11332-018-0521-7
8. J. Gustavo Claudino, et. al., CrossFit Overview: Systematic Review and Meta-analysis Sports Med Open. **4**, 11 (2018). doi: 10.1186/s40798-018-0124-5
9. I.N. Tyurjn, V.V. Getmantseva, E.G. Andreeva, V.S. Belgorodskiy, Izvestiya Vysshikh Uchebnykh Zavedenii, Seriya Teknologiya Tekstil'noi Promyshlennosti **378 (6),** 131–140 (2018)
10. H. Baskan, et. al., *Running functional sport vest and short for e-textile applications.* In Proc. AUTEX 2017 conference proceedings (2017)
11. R. Atakan, *Design of an Electronic Chest-Band*. In Proc. AUTEX 2017 conference proceedings (2017)
12. J. He, et. al., Sensors **17(6),** 1393 (2017) https://doi.org/10.3390/s17061393
13. S. Jung, et. al., Scientific Reports **5,** 17081 (2015)
14. I.N. Tyurin, V.V. Getmantseva, S.S. Tashpulatov, et al*., Numerical Simulation of the Pressure of a Compression Shell for Sports Purposes.* Fibre Chem (2023). https://doi.org/10.1007/s10692-023-10403-z
15. I. Tyurin, S. Tashpulatov, V. Belgorodsky, E. Andreeva, E3S Web Conf. **371,** 02055 (2023) https://doi.org/10.1051/e3sconf/202337102055
16. I.N. Tyurin, V.V. Getmantseva, E.G. Andreeva, Fibre Chem. (2018). https://doi.org/10.1007/s10692-018-9918-y
17. I.N. Tyurin, V.V. Getmantseva, E.G. Andreeva, Fibre Chemistry **51(2),** 139-146 (2019)
18. I.N. Tyurin, A.M. Yakovlev, E.G. Andreeva, S.S.H. Tashpulatov, V.S. Belgorodsky, Izvestiya Vysshikh Uchebnykh Zavedenii, Seriya Teknologiya Tekstil'noi Promyshlennostithis **(6),** 179–183 (2020)