BRAIN. Broad Research in Artificial Intelligence and Neuroscience
ISSN: 2068-0473 | e-ISSN: 2067-3957
Covered in: Web of Science (WOS); PubMed.gov; IndexCopernicus; The Linguist List; Google Academic; Ulrichs; getCITED; Genamics JournalSeek; J-Gate; SHERPA/RoMEO; Dayang Journal System; Public Knowledge Project; BIUM; NewJour; ArticleReach Direct; Link+; CSB; CiteSeerX; Socolar; KVK; WorldCat; CrossRef; Ideas RePeC; Econpapers; Socionet.

2020, Volume 11, Issue 4, Sup.1, pages: 01-12 | https://doi.org/10.18662/brain/11.4Sup1/152

Muscle Coactivation Index Improvement in Junior Handball Players by Using Propioceptive Exercises

Bogdan ANTOHE[1]*, Marinela RAȚĂ[2], Gloria RAȚĂ[3]

[1] National University of Physical Education and Sports, Faculty of Physical Education and Sport, Bucharest, Romania, antohe_bogdan@yahoo.com
* *Corresponding author*

[2] "Vasile Alecsandri" University of Bacău, Faculty of Movement, Sport and Health Sciences, 157 Calea Mărăşeşti, Bacău, Romania.

[3] "Vasile Alecsandri" University of Bacău, Faculty of Movement, Sport and Health Sciences, 157 Calea Mărăşeşti, Bacău, Romania.

Abstract: *Ankle sprain is the most common injury in performance sports. Two of the most common residual symptoms of an ankle sprain are: the occurrence of chronic joint instability and agonist-antagonist muscle imbalances, expressed numerically by the values of the muscle coactivation index. The purpose of the research was to demonstrate that the use of proprioceptive exercises leads to the improvement of the degree of chronic joint instability and of the values of the muscle coactivation index. The research had a number of 22 subjects, handball players, whose age was between 15 and 16 years. The degree of joint instability was established by using the "Foot and Ankle Disability Index" Questionnaire, while the values of the muscle coactivation index were calculated following the electromyographic measurements. The obtained results highlight the efficiency of the proposed proprioceptive exercise programme, the statistical significance of the obtained results (by improving the initial and final values), as well as the existence of correlations between all evaluated parameters (muscle coactivation index, number of ankle sprains and degree of joint instability). The conclusions of the research underline the efficiency of proprioceptive exercises in diminishing the degree of chronic joint instability and in improving the values of the muscle coactivation index. Based on the results obtained, the research acquires an important practical value, because the proposed intervention programme has applicability in all sports sectors.*

Keywords: *coactivation; index; agonist; antagonist.*

How to cite: Antohe, B., Rață, M., & Rață, G. (2020). Muscle Coactivation Index Improvement in Junior Handball Players by Using Propioceptive Exercises. *BRAIN. Broad Research in Artificial Intelligence and Neuroscience, 11*(4Sup1), 01-12. https://doi.org/10.18662/brain/11.4Sup1/152

Introduction

Ankle sprain is a traumatic condition of the talocrural joint, caused by a movement that exceeds the physiological limits of joint amplitude and which results in a stretching or rupture of the ligaments (Fong et al., 2007).

Both nationally and internationally, in handball, the ankle sprain occupies a secondary place in the top of injuries (the chances of injury are 67.8%, over a period of two years), the main joint prone to injuries being the knee (Curitianu & Balint, 2015; Mircioaga, 2010).

Muscle coactivation is the phenomenon by which the contraction of the agonist muscle is accompanied by the contraction of the antagonist muscle, but at a lower intensity. The most studied form of muscle coactivation is the antagonistic one, and in the specialty literature it is also known as co-contraction (Beck, 2015). The muscle coactivation index (CI) is the way to measure the degree of muscle coactivation.

At present, muscle balance can be evaluated by surface electromyography. The first research on muscle coactivation was done in the 19th century by Sherrington (1897), who proposed the theory of mutual inhibition. This theory supports the idea according to which "a contraction of the agonist muscle leads to the reflex inhibition of the antagonist muscle." The causes of muscle imbalances can be multiple, but the most common ones are as follows: practising sports events which require more than one part of the body, improper warm-up of athletes, the existence of severe postural deficits, the selective toning of a single muscle group, etc. (Herzog et al., 2019). The degree of muscle coactivation is one of the most used parameters for qualitative evaluation of the neuromuscular function. It can be correlated with the sports performance, with the risk of accidents or with the evolution in the recovery process of injured athletes.

The importance of muscle coactivation on the qualitative parameters of the movement arises from its role in: increasing joint stability, dynamic protection of the ligaments, improving motor control, increasing the reaction time of the muscles (Liebenson, 2007). Cordun (1999) states that "the interaction between the agonist and antagonist muscles increases the movement precision, moreover a greater the number of muscles being involved."

Muscle coactivation is a phenomenon present in all movements of the human body, which has higher values during the development of motor acts on unstable support surfaces. Significant and unjustified increases in muscle coactivation index values denote "the immaturity of the motor control system, and in subjects with chronic joint instability, increasing muscle coactivation is considered a strategy adopted by the motor control system, whose role is to provide joint stability" (Masso et al., 2010). The lower the percentage values of the muscle coactivation index are, the better the ability of the motor control system to cope with more complex motor tasks is (Zuniga et al., 2018).

It has been shown that the proprioceptive exercises decrease the latency time required to activate the ankle muscles, so they can improve the values of the muscle coactivation index. In addition, the proprioceptive training restores the pathways of transmitting the sensory information between the mechanoreceptors and the central nervous system and stimulates the secondary sensory pathways, which play an important role in compensating for the proprioceptive deficits, arising from accidents.

In conclusion, by systematically applying a programme of proprioceptive exercises, we can obtain improvements in the muscle coactivation index. These improvements will have a positive effect on the ankle sprain prevention and treatment.

Material and method

Research subjects

The number of subjects included in the experiment was 22. These are members of the men's handball team (junior II), of the Bacău Municipal Sports Club (table 1). The research was carried out in Bacău City, at the sports hall of the "Stephen the Great" National Pedagogical College. The duration of the research was six months. The initial evaluation took place between 09 - 29.09.2019, and the final one during the period of 27.01.2019 - 12.02.2019.

The purpose of the research is to highlight the importance of using proprioceptive exercises in improving the values of muscle coactivation index and joint instability, as well as in reducing the number of ankle sprains in handball players.

The objectives of the research were the following: carrying out an objective evaluation, by which we highlight the changes in the values of the muscle coactivation index, of the joint stability and of the number of ankle sprains; elaboration and implementation of a programme of proprioceptive exercises, through which we can obtain the improvement of the values of the muscle coactivation index, of the joint instability and of the number of ankle sprains, in the handball athletes.

The research hypotheses were the following: performing an applied intervention by using proprioceptive exercises which leads to the improvement of the values of the muscle coactivation index; performing an applied intervention by using proprioceptive exercises which leads to the diminishing of the number of ankle sprains and to the improvement of the degree of joint stability.

The methods used in the research were the theoretical documentation, the pedagogical observation, the experimental method, the method of tests and evaluation tests, the survey method, the method of recording and statistical-mathematical processing of the data.

Subject evaluation

In the evaluation of the subjects we used the anthropometric measurements to assess the level of physical development of athletes (height, weight and body mass index) and the "Identification of Functional Ankle Instability (IdFAI)" questionnaire in order to assess the degree of joint instability.

For the assessment of the muscle coactivation index, we used the surface electromyography (Biopac MP36, Biopac System Inc., Santa Barbara, CA). Before starting the evaluation and the positioning of the electrodes, we cleaned the skin, applied conductive gel and calibrated the recording unit. The data recording was done through 2 acquisition channels, whose recording frequency was 1000 Hz. The muscles evaluated were the anterior tibial and sural triceps. In order to position the electrodes in identical anatomical landmarks, at the level of the anterior tibial muscle, they were positioned 3 cm lower and 1 cm medial of the tibial tuberosity. For the sural triceps muscle, the electrodes were applied 4 centimeters below the popliteal fossa. In order not to influence the obtained results, the neutral electrodes were positioned at the basin level, on the iliac ridges, and the subjects performed the event barefeet.

In order to calculate the muscle CI values at the ankle muscles, on the plantar flexion motion, we considered the application of the formula proposed by Kellis, Arabatzi & Papadopoulos (2003), (Ec. 1):

$$\mathrm{CI} = \frac{2Iant}{Itotal} * 100$$

Ec. 1 – **calculation formula for the muscle coactivation index**

This formula was applied for the agonist action of the sural triceps muscle and the antagonistic action of the anterior tibial muscle (Fig. 1).

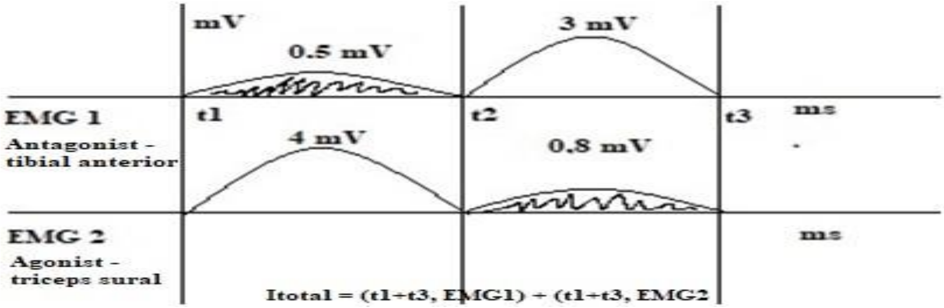

Fig. 1. Schematic representation of the electromyographic wave and the method of calculating the muscle coactivation index, according to the formula proposed by Kellis, Arabatzi & Papadopoulos (2003). The hatched area represents the area of electromyographic activity of the antagonist muscle.

(*Legend:* EMG = electromyography, mV = millivolts, ms = milliseconds, t = time. To obtain the muscle CI values for the example above, we will apply the following formula: $\mathrm{CI} = \frac{2*(0,5+0,8)}{0,5+3+4+0,8} * 100$ = 31%. The percentage obtained represents the degree of coactivation of the anterior tibial muscle, compared to the triceps sural muscle).
Source: This figure was designed by the authors

Applied intervention

The duration of the exercise programme was 15 weeks. The exercises were performed at the beginning of each training session and lasted from 15 to 20 minutes. The frequency of application of the exercise programme was three workouts per week. The exercises performed were as follows: static balance exercises performed from unipodal and bipodal support on a stable and unstable surface, dynamic balance exercises performed from unipodal and bipodal support on a stable and unstable surface. As teaching materials we used: balance board, inflatable balance disc, gym bench, balance brick, modular ladder for speed training, rhythmic gymnastics circle and plastic hurdles.

Results

The initial and final results obtained by the athletes in the evaluation events are presented in table 1. The statistical data analysis was performed in tables 2 and 3, using IBM SPSS Statistics software, version 20.

Table 1 Initial and final results obtained by the athletes in the evaluation events

Subiects included in the experiment													
S	**H (cm)**		**W (kg)**		**BMI**		**POF**	**NE**		**GI (points)**		**CI (%)**	
	I	**F**	**I**	**F**	**I**	**F**		**I**	**F**	**I**	**F**	**I**	**F**
1. A.A.	175	175	65	66	21.2	21.5	LW	0	0	2	0	62	44
2. B.A.	189	191	82	92	22.9	25.2	P	1	0	3	1	64	59
3. C.D.	182	183	88	92	26.5	27.5	RW	1	1	18	15	83	66
4. F.R	197	202	85	90	21.3	22	LI	5	0	28	11	98	81
5. D.D	180	180	91	93	28	28.7	RI	1	0	8	0	53	48
6. D.G.	179	180	57	60	17.8	18.5	LW	7	3	30	19	86	79
7. L.C	180	181	65	68	20	2.07	PI	0	0	2	0	85	81
8. M.A.	182	182	73	76	22	22.9	PI	0	0	1	0	48	45
9. M.E.	177	178	85	86	27.1	27.2	RW	0	0	1	0	47	45
10. T.T.	190	193	70	70	19.4	18.8	LI	0	0	12	0	71	47
11. T.M.	193	195	79	81	21.2	21.3	PI	0	0	0	0	69	62
12. A.Ș.	183	184	68	69	20.3	20.4	LW	5	1	25	11	73	71
13. C.R.	180	183	80	83	23.1	24.8	PI	7	0	25	13	89	71
14. D.A.	186	190	68	70	19.7	19.3	RI	4	1	25	24	82	72
15. P.I.	191	194	78	85	21.4	22	RI	1	1	9	9	65	52
16. F.D.	188	190	67	69	18.9	19.1	RW	2	0	12	8	66	54
17. D.K.	176	178	62	65	20	21	LW	0	0	3	0	40	38
18. G.C.	199	202	84	87	21.2	21.3	PI	1	0	7	7	75	65
19. B.D.	187	191	75	78	21.4	21.4	C	1	1	12	6	68	48
20. R.R.	184	186	85	86	26	24.9	C	3	0	21	15	70	56
21. S.F.	186	190	86	90	24.5	24.9	P	4	2	14	10	86	67
22. G.S	187	187	80	85	22.9	24.3	RI	1	0	14	4	70	58

Legend: S = subject, H = height, W = weight, BMI = body mass index, POF = position occupied in the field (LW = left winger, RW = right winger, G = goalkeeper, PI = pivot, RI = right inter , LI = left inter, C = centre), NS = number of ankle sprains, DI = degree of instability of the ankle joint, CI = muscle coactivation index, I = initial, F = final.

Source: authors' own contribution

Table 2. T-Student test results and Cohen's D coefficient

	NS		**DI**		**CI**	
	I	F	I	F	I	F
Number of subjects	22	22	22	22	22	22
Mean	2	0.454	12.36	6.954	70.45	59.50
Standard deviation	2.309	0.800	9.776	7.174	14.75	12.92
Student's test	3.636		4.952		7.596	
P* value	< 0.02		< 0.01		<0.01	
Cohen's D	0.900		0.630		0.789	

** Results in initial and final testing by applying the Student's dependent t-test to each of the two groups. A significant difference between the two tests if p < 0.05.*
Legend: NS= number of ankle spains. DI = degree of instability of the ankle joint. CI = muscle coactivation index

Source: results from the statistical processing of data arising from original research

Table 3. Pearson Corelation

Pearson Correlations			
	ns_f	**di_f**	**ci_f**
ns_f	1		
di_f	**.601****	1	
ci_f	**0.391**	**.593****	1

***. Correlation is significant at the 0.01 level (2-tailed), *. Correlation is significant at the 0.05 level (2-tailed). Legend: h_i = initial height, h_f = final height, w_i = initial weight, wg_f = final weight, bmi_i = initial body mass index, bmi_f = final body mass index, ns_i = initial number of ankle sprains, ns_f = final number of ankle sprains, di_i = initial degree of instability, di_f = final degree of instability, ci_i = initial coactivation index, ci_f = final coactivation index.*

Source: results from the statistical processing of data arising from original research

For the statistical analysis of the obtained results, we used the T-Student test and the Cohen's D coefficient. From the results presented in table 2, we highlight a series of aspects:

– the analysis of the initial (M = 2, SD = 2,309) and final (M = 0.454, SD = 0.800) results of the number of ankle sprains indicates the statistical significance of the results, t = (3,636), p = 0.02. Cohen's coefficient values (D = 0.900) suggest a major effect of the exercise programme applied;

– the analysis of the initial (M = 12.36, SD = 9.776) and final (M = 6.954, SD = 7.174) results of the degree of joint instability indicates the statistical significance of the data, t = (4.952), p = 0.01. Cohen's values (D = 0.630) suggest an average effect of the exercise programme applied;

- the analysis of the initial (M = 70.45, SD = 14.75) and f + -initial (M = 59.50, SD = 12.92) results of the muscle coactivation index indicates the statistical significance of the data, t = (7,596) , p = 0.01. Cohen's coefficient values (D = 0.789) suggest a major effect of the applied exercise programme.

Following the application of the Pearson test (table 3), we found that there is a positive correlation between:

– the number of ankle sprains and the degree of joint instability (r = 0.601);

– the degree of joint instability and the muscle coactivation index (r = 0.593).

Discussions

Following the analysis of the results presented in tables 1, 2 and 3, for the 22 subjects, we present a number of issues.

The initial and final analysis of the results recorded by the whole group of athletes indicates an initial average height value of 185 cm and a final average value of 187 cm. Regarding the average values of body weight, they increased by 3.1 kg, from the initial average value of 76 kg, to the final average value of 79.1 kg. These changes in body height and weight correspond to a decrease of the average values of the body mass index by 0.4 points, from the initial average value of 22.1 points, to the final average value of 21.7 points.

Although each athlete has his/her own rate of growth and development, in the specialty literature, height and weight are considered risk factors for the occurence of ankle sprains, thus affecting the values of the muscle coactivation index. The justification offered by the specialists is the following: when the ankle is in a risky position (inversion + supination), an increased body weight and height will increase the couple of forces acting on the lateral ligament complex, responsible for limiting the inversion movement, Correia & Torres (2019), Beynnon, Murphy & Alosa (2002). All athletes achieved increases in height and body weight, in varying proportions. These improvements are considered normal at this (puberty) age stage, characterized by a growth pattern in boys.

In the specialized literature, several risk factors responsible for the occurrence of an accident are presented. These are: the existence of a previous injury, the position occupied in the field, the installation of muscle fatigue and the occurence of muscle imbalances (McCall et al., 2015).

Regarding the existence of a previous injury, following the analysis of the final results, we found that athletes who suffered a higher number of ankle sprains, have higher values of the degree of joint instability and muscle coactivation index.

Regarding the position occupied on the field, the players from the second line (inters and pivots), are more prone to injuries, because these positions require repeated jumps (Mónaco et al., 2019). Analyzing the number of ankle sprains, we found that the inters are the most prone to sprains, followed by wingers and pivots.

The degree of chronic joint instability is also a risk factor for accidents. It has been shown that athletes who have mechanical and proprioceptive deficits (limitations of joint mobility or sensory deficits), which occur after the ankle sprain, may undergo changes in the degree of joint stability (Theisen & Day 2019). In our research, at the initial evaluation, the athletes presented an average value of joint instability of 12.3 points. The decrease of these values to 6.9 points, at the final evaluation, indicates the existence of mechanical and proprioceptive deficits, as well as the efficiency of the applied exercise program. In addition, the positive correlation between the final number of ankle sprains and the final degree of joint instability (r = 0.601), highlights the negative consequences of an ankle sprain on joint stability.

Brown et al. (2004) demonstrated a decrease in the electromyographic activity of the sural triceps muscle, during the landing on the floor, in subjects with chronic joint instability. In another research, Jaber et al. (2018) demonstrated a 33% decrease in the electromyographic activity of the anterior tibial muscle, when a dynamic balance test was applied to subjects with chronic joint instability. These changes in the electromyographic activity of the agonist and antagonistic muscle groups, in athletes with chronic joint instability, produce changes in the values of the muscle coactivation index.

The improvements in the muscle coactivation index obtained in this research were 10.95%. The values of the Cohen's coefficient (D = 0.789) indicate a major effect, obtained by performing the exercise programme, on the values of the muscle coactivation index. We consider that there is a direct link between the degree of joint instability and the muscle coactivation index (r = 0.593), which allows us to state the following reasoning: the higher the number of ankle sprains suffered by an athlete is, the higher the degree of joint instability is, which will increase the values of the muscle coactivation index.

Other factors that influence the degree of muscle coactivation are: speed of movement execution (Iwamoto et al., 2017), age of the subjects and surface area used (Gebel et al., 2019). *The higher the postural demands generated by the support surface, the higher the values of the muscle coactivation index.*

The results obtained in our research are of particular practical importance, as they underline the positive effects of applying proprioceptive exercises on the improvement of mechanical (by reducing the degree of joint instability) and neuromuscular (quantified by improving the values of muscle coactivation index) of the joint. The occurrence of these changes is accounted for by the central inhibitory feed-back mechanisms, which lead to the reorganization of the sensory-motor cortex (Aman et al., 2015). For the moment, these investigations are at the beginning, the neurological mechanisms that manage muscle coactivation are still incompletely discovered and deciphered.

Conclusions

Starting from the proposed purpose, pursuing the objectives and hypotheses, we concluded that the application of a program of proprioceptive exercises, led to the improvement of the muscle coactivation index with an average value of 10.92%, to the handball players with chronic joint instability of ankle joint and reducing the number of sprains with an average value of 1.35 sprains. These findings allow us to emphasize that:

- the hypothesis according to which *"carrying out an applied intervention by using proprioceptive exercises leads to the improvement of the values of the muscle coactivation index"* was confirmed and is justified by the improvement of the final values of the muscle coactivation index;

- the hypothesis according to which "carrying out an applied intervention by using proprioceptive exercises leads to a decrease in the number of ankle sprains and to the improvement of the degree of joint stability" has been confirmed and is justified by the improvement of the final values of the degree of joint instability and the decrease in the number of ankle sprains.

We believe that our research has fulfilled its purpose.

References

Aman, J. E., Elangovan, N., Yeh, I. L., & Konczak, J. (2015). The effectiveness of proprioceptive training for improving motor function: a systematic review. *Frontiers in human neuroscience*, *8*, 1075. https://doi.org/10.3389/fnhum.2014.01075

Beck, T. (2015). Electromyographic Cross-Spectral Analysis of Antagonist Muscle Coactivation. *International Journal of Sports and Exercise Medicine, 1*, 001. https://doi.org/10.23937/2469-5718/1510001

Beynnon, B.D., Murphy, D.F., & Alosa, D.M. (2002). Predictive Factors for Lateral Ankle Sprains: A Literature Review. *Journal of Athletic Training*, *37*(4), 376–380.

Brown, C., Ross, S., Mynark, R., & Guskiewicz, K. (2004). Assessing Functional Ankle Instability with Joint Position Sense, Time to Stabilization, and Electromyography. *Journal of Sport Rehabilitation, 13*(2), 122–134. https://doi.org/10.1123/jsr.13.2.122

Cordun, M. (1999). *Kinetologie medicală* [Medical Kinetology]. Axa.

Correia, M.A.C., & Torres, J. (2019). Intrinsic and Extrinsic Risk Factors for Lateral Ankle Sprain: A Literature Review. *Archives of Sports Medicine*, *3*(2), 172-177. https://doi.org/10.36959/987/247

Curitianu, I. M. & Balint, E. (2015). Injuries and their prevention in the handball game. *Journal Of Social Science Research*, *7*(2), 1271–1275. https://doi.org/10.24297/jssr.v7i2.3570

Fong, D. T.P., Hong, Y., Chan, L.-K., Yung, P. S.-H., & Chan, K.-M. (2007). A Systematic Review on Ankle Injury and Ankle Sprain in Sports. *Sports Medicine*, *37*(1), 73–94. https://doi.org/10.2165/00007256-200737010-00006

Gebel, A., Lüder, B., & Granacher, U. (2019). Effects of Increasing Balance Task Difficulty on Postural Sway and Muscle Activity in Healthy Adolescents. *Frontiers in Physiology*, *10*. http://doi:10.3389/fphys.2019.01135

Herzog, M. M., Kerr, Z. Y., Marshall, S. W. & Wikstrom, E. A. (2019). Epidemiology of Ankle Sprains and Chronic Ankle Instability. *Journal of Athletic Training, 54*(6), 603–610. https://doi.org/10.4085/1062-6050-447-17

Iwamoto, Y., Takahashi, M., & Shinkoda, K. (2017). Correction to: Differences of muscle co-contraction of the ankle joint between young and elderly adults during dynamic postural control at different speeds. *Journal of Physiological Anthropology*, *36*(1), 36-38. http://doi:10.1186/s40101-017-0154-6

Jaber, H., Lohman, E., Daher, N., Bains, G., Nagaraj, A., Mayekar, P., & Alameri, M. (2018). Neuromuscular control of ankle and hip during performance of the star excursion balance test in subjects with and without chronic ankle instability. *PLOS ONE, 13*(8), e0201479. https://doi.org/10.1371/journal.pone.0201479

Kellis, E., Arabatzi, F. & Papadopoulos, C. (2003). Muscle co-activation around the knee in drop jumping using the co-contraction index. *Journal of Electromyography and Kinesiology, 13*, 229–238. https://doi.org/10.1016/S1050-6411(03)00020-8

Liebenson, C. (2007). *Rehabilitation of the Spine A Practitioner's Manual.* Lippincott Williams & Wilkins.

Masso, N., Rey, F., Romero, D., Gual, G., Costa, L. & German, A. (2010). Surface electromyography applications in the sport. *Apunts medicina de l'esport,* 45(165), 121-130.

McCall, A., Carling, C., & Davison, M. (2015). Injury risk factors, screening tests and preventative strategies: a systematic review of the evidence that underpins the perceptions and practices of 44 football (soccer) teams from various premier leagues. *British Journal of Sports Medicine, 49*(9), 583–589. https://doi.org/10.1136/bjsports-2014-094104

Mircioagă, E. D. (2010). Performanța sportivă și traumatismele specifice jocului de handbal în funcție de segmentul afectat (Sports performance and injuries specific to the game of handball depending on the affected segment). Discobolul, VI, 4 (22).

http://www.unefs.ro/custom_images/file/discobol%20pdf/arhiva/Discobolul%20nr%2022%20decembrie%202010/cuprins/11.pdf

Mónaco, M., Rincón, J., Ronsano, B., Whiteley, R., Sanz-Lopez, F., & Rodas, G. (2019). Injury incidence and injury patterns by category, player position, and maturation in elite male handball elite players. *Biology of sport*, *36*(1), 67–74. https://doi.org/10.5114/biolsport.2018.78908

Sherrington, C. S. (1897). On reciprocal innervation of antagonistic muscles. Third note. *Proceedings of the Royal Society of London, 60*, 414-417. https://doi.org/10.1098/rspl.1896.0062

Theisen, A., & Day, J. (2019). Chronic Ankle Instability Leads to Lower Extremity Kinematic Changes During Landing Tasks: A Systematic Review. *International Journal of Exercise Science*, 12(1), 24–33.

Zuniga, J., Dimitrios, K., Peck, J., Srivastava, R., Pierce, J., Dudley, D. et al., (2018). Coactivation index of children with congenital upper limb reduction deficiencies before and after using a wrist-driven 3D printed partial hand prosthesis. *Journal of NeuroEngineering and Rehabilitation, 15*(1), 48. https://doi.org/10.1186/s12984-018-0392-9