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IMPORTANCE OF COORDINATION MOTOR ABILITIES IN EXPERT-LEVEL ON-SIGHT SPORT CLIMBING

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Abstract

Objective: The primary aim of this study was to examine the level of selected coordination motor abilities in expert sport climbers compared to a non-climber control group. The study also attempted to establish a hierarchy of the motor abilities studied with respect to the scores obtained during competitions.

Methods: The material for the study consisted of the results from examination of 10 expert rock climbers. Average *on – sight* climbing scores the athletes had achieved before the study was 7c on a French scale. The control group comprised 15 untrained students from full-time physical education courses at the University School of Physical Education in Cracow. All the subjects performed computer tests of motor abilities as proposed by Jaworski. Evaluation of the climbing performance was based on the best score obtained during on-sight rock climbing. The data collected were analysed using simple statistical methods by calculating mean and SD in both groups studied, and the differences between the groups studied were verified using t-Students or Mann-Whitney statistics. Furthermore, we compared Spearman's rank correlation coefficients between competitive level and coordination motor abilities.

Results and conclusions: Higher scores in the coordination motor abilities studied were found in the athletes involved in climbing compared to the group of untrained subjects. Motor abilities that favour improved rock climbing are speed, accuracy and precision of movements and the ability of kinaesthetic differentiation of spatial-dynamic parameters. Analysis of a coordination profile of the best athlete suggests that coordination motor abilities should be considered during selection, recruitment and training of climbers.

Keywords: *sport climbing, coordination motor abilities, on-sight climbing*

Introduction

Sport climbing is a form of rock climbing that derives from mountain climbing and is now gaining in popularity. The sport can be practised in both rock and on artificial climbing walls [1,2]. The aim in this sport is to ascend a climbing route with a highest possible difficulty level. Routes can be climbed using several styles, with on-sight being the most valued[1]. Climbing routes have their own grades which correspond to specific scales. The most popular grading system in Europe is French numerical scale. This system uses a symbolic representation of difficulty of a climbing route (Roman letters and Arabic numerals and a plus sign). A climbing route 6a, for instance, is easier to climb than 6b, while 6b is easier than 6b+ [3]. The most difficult routes which are climbed on-sight in Poland are 8b. In the world, the hardest on-sight routes climbed are around 9a. It seems essential in rock climbing to determine specific factors that affect performance during competition (a "champion profile"). Numerous researchers have argued that the factors that mold a champion profile in climbing include sport-specific body build and energy-related capabilities [1-10].

Analysis of on-sight climbing style suggests that being successful in the sport does not depend solely on fitness but also on technique and certain coordination motor abilities (CMA) of a climber [11]. Sport climbing was classified in a group of sports which are characterized by high variability of movement structure. This is mainly due to the pattern of stimuli from the outside. Similarly, open movement structures (which are typical of climbing) are also used in team games, combat sports, Alpine skiing or white water kayaking. Using the hierarchical classification of coordination abilities, climbing can be described as the 3rd and 4th level. The third level is understood to mean the ability of accurate and slow control and regulation of unpredictable motor activities under variable conditions (accuracy + variability); ability of precision movement control under variable situations [12,13]. When climbing, there are places at a climbing route that do not require much acceleration. This means a slow reaching down small holds, which requires

[1] On-sight (OS) means clean climbing a route without prior practice in this place on the first attempt and without falling. This means that a climber has never attempted to ascend the route, never familiarized with it by abseiling using a rope and never watched anybody climbing the route. It is essential that the climber does not have any information about the way the route can be climbed.

substantial static strength. The third level also means climbing a relatively easy route. Lack of precision or ability to adapt to variable conditions of climbing routes might cause huge waste of energy. Furthermore, the fourth level refers to abilities of precise control and regulation of the unpredictable and fast activities under variable conditions and situations (accuracy + speed + variability); ability of adequate motor adjustment and adaptation under conditions of temporal deficit. In climbing, this means that a climber performs moves on the verge of their physical capabilities, often automatically.

Previous publications on technical and tactical skills and coordination abilities have emphasized that kinaesthetic and visual impressions are critical in this sport [14-17]. The quality of this information is likely to be facilitated by proper alignment of body in the climbing space (gravitational field). In practice, it is important to properly evaluate the layout of holds and footholds and assessment of the difficulty of a sequence of climbing movements and rock shape. High perception abilities i.e. efficiency of visual analyser and proprioceptors might considerably improve quality of performing climbing activities. Results of the studies [17] have demonstrated that coordination abilities are likely to determine climbing quality at the expert level. Elite climbers were characterized by higher coordination compared to beginners. In the light of these findings, the particular role is played by high spatial orientation and, more specifically, one of its components which is perception. This variable explains in 27% the performance on a climbing wall [17].

Coordination abilities considered with respect to the problems related to sport climbing have not been sufficiently researched in the available literature to date [9]. With regard to the above observations, the following research questions have been asked:

1. What is the level of coordination abilities in the climbers studied compared to untrained controls (university students)?
2. Which ability or a group of coordination abilities might specifically determine climbing quality at the expert level?

Methods

Participants

The material of the study consisted of the results collected from 10 male subjects (mean age = 23.4, standard deviation = 5.5 yrs) who were expert rock climbers. Average training experience of the climbers was 10.3 ± 4.0 yrs. Average *on – sight* climbing scores the athletes had achieved before the study was 7c on a French scale [3]. The control group was comprised of 15 students (20.9 1.3 yrs) from the University School of Physical Education in Krakow. The study recruited only university students who had never been involved in any sports before. Therefore, it can be adopted that they were a homogeneous group in terms of the level of motor skills and abilities. The examinations of both groups were carried out in the Anthropomotorics Laboratory (University School of Physical Education in Cracow) from 3 p.m. to 6 p.m. For the purposes of the present study, the degrees of difficulty on the French scale [3] were replaced by the notation in Arabic numerals (Table 1).

A high level of climbing performance in the group was confirmed by the ability to climb 7c routes *on sight* (OS) reported in Polish climbing media. Furthermore, the best athlete (case study) had even achieved a score of 8b on the French scale. Evaluation of the individual skill level of the climbers studied was based on the best scores obtained during on-sight rock climbing.

Procedures

Based on the most modern classifications of coordination motor skills (the analysis of the problem

Table 1. *Characterization of the group of climbers and comparison between the French scale with the numerical scale [4]*

Climber	Chronological age	Training experience (years)	OS French scale	Numerical scale
W	23	13	8b	4.50
WO	30	15	8a	4.00
F	17	6	8a	4.00
K	17	6	7b+	3.25
S	27	8	7b+	3.25
L	23	8	7b+	3.25
L. M	20	9	7b	3.00
R	34	18	7b+	3.25
Ś	23	8	7b+	3.25
M	20	12	8a	4.00

OS – *„on – sight”*

is contained in [18], the scope of the examinations included: kinaesthetic differentiation of movements (temporal and spatial parameters), spatial and dynamic kinaesthetic differentiation, frequency of movements, mean time of simple reaction (to visual and auditory stimuli), mean time of selective reaction, spatial orientation, visual-motor coordination, rhythmization and speed, precision and accuracy of movements. A procedure for each of the tests can be briefly described as follows [19]:

- kinaesthetic differentiation (spatial parameters, temporal parameters): a subject predicted the time necessary for filling the rectangle, the result of the test was mean absolute deviation from the pattern expressed in pixels,
- frequency of movements: within the timeframe of 15 seconds, a subject touched two squares alternately with a tablet pen; the result was expressed in the number of touches,
- visual and auditory reaction time: after presentation of a stimulus, a subject was supposed to click the left button of a mouse as quickly as possible; the result was expressed in milliseconds,
- complex reaction time: depending on the stimulus (auditory or visual), a subject clicked a respective button of a mouse as quickly as possible, the result was expressed in milliseconds,
- speed, precision and accuracy (time and mistakes): the subject was supposed to drag a square with a tablet pen through a special maze, as quickly as possible and with possibly lower number of mistakes; result of the test was expressed in seconds and number of mistakes,
- rhythmization: the subject was supposed to remember the rhythm presented by the computer and then to reproduce it; the result was expressed in milliseconds,
- spatial orientation (time and mistakes): a subject used a tablet pen to change the sequence of two squares which were displayed on intersection of perpendicular lines as quickly as possible; the result was expressed in seconds and numbers of mistakes,
- visual and motor coordination (time and mistakes): a subject used a tablet pen to touch the square generated by the program as quickly as possible; the result was expressed in seconds and numbers of mistakes.
- spatial and dynamic kinaesthetic differentiation (time and mistakes) - a subject was asked to touch 100 randomly displayed squares with a tablet pen as fast as possible; the result was expressed in seconds and numbers of mistakes.

The study design used a computer test battery to evaluate of selected coordination abilities [20], with reliability expressed with ICC coefficient regarded as sufficient for this type of research tools. Reliability of the tests used was similar to the Vienna Testing System [21] – ICC = 0.50 - 0.99). The reliability coefficients obtained are also consistent with the requirements propounded by other researchers [22] and the results presented in comparative studies [23-26]. The correlation coefficients of the results obtained using the authors' test battery with the results recorded by conventional psychotechnical apparatus (visual motor testing device, Piórkowski's apparatus, MRK-80) ranged from 0.70 to 0.86 [27], which pointed to their statistical validity [28].

Statistical analysis

The basic descriptive statistics were computed for the motor coordination abilities tested in the group of climbers and untrained controls. Significance of differences between the groups studied was tested by means of *t*-Students or Mann-Whitney statistics, depending on the distribution of the coordination ability tested. We computed the indices of the normalized differences for all the parameters between the results from the group of climbers and untrained students. Normalization was performed with respect to the arithmetic mean and standard deviation obtained in students.

Spearman's rank correlation coefficient was calculated between rock climbing level and coordination abilities studied. With respect to spatial and dynamic kinaesthetic differentiation, spatial orientation, visual-motor coordination and speed, accuracy and precision of movements, the computation was also performed using the indices which represented the total of the normalized results obtained for an athlete tested with respect to the number of mistakes made and the time of performing the test.

Two groups were separated based on the achievements in rock climbing, depending on the sport skill level (n=6 for climbers who had achieved more than 8a OS and $n = 4$ for climbers who had climbed routes with level of difficulty of minimum 8a OS) – (top level athletes and lower level athletes, see Table 2).

Then, the best athlete was selected (case study) in order for a profile of his scores recorded in the coordination abilities tests to be illustrated as compared to the group of other climbers and untrained controls.

The computations were carried out using STATISTICA 6.0 PL for Windows software. Level of statistical significance was set at $P \leq 0.05$.

Results

Comparison of coordination abilities of climbers with university students of physical education

It was found that the differences in all coordination abilities between the groups of climbers with different sport skill level were statistically insignificant (see Table 2). This allowed for combining climbers into one group, which was compared to the untrained controls.

Table 2. *Basic statical characteristics of CMAs studied and significance of differences between climbers in total and students with normalized differences (z)*

Variable	Measurement unit	Climbers-Group 1♦	Climbers-Group 2♦♦	Climbers Total		Students		Statistics	P	z
		$\bar{x}$	$\bar{x}$	$\bar{x}$	SD	$\bar{x}$	SD			
Kinaesthetic differentiation – spatial parameters	Deviation from the model / pixel	10.5	12.3	11.6	5.8	12.9	5.3	66.0*	0.61	-0.24
Kinaesthetic differentiation – temporal parameters	Deviation from the model / pixel	28.7	36.5	33.4	20.4	50.6	21.4	52.5*	0.21	-0.80
Spatial and dynamic kinaesthetic differentiation	Time / s	53.0	56.6	55.2	15.2	63.6	12.6	1.5	0.14	-0.66
Spatial and dynamic kinaesthetic differentiation	Number of mistakes / n	9.0	9.5	9.3	6.3	11.8	7.9	65.0*	0.57	-0.31
Frequency of movements	n touches	43.2	44.8	44.2	6.0	39.5	9.7	1.3	0.19	0.48
Visual reaction time	Time / ms	245.0	230.5	236.3	18.9	237.6	23.6	71.0*	0.82	-0.05
Auditory reaction time	Time / ms	205.5	202.1	203.5	19.5	215.5	22.9	1.3	0.18	-0.52
Complex reaction time	Time / ms	421.2	397.6	407.1	76.6	388.8	58.2	0.6	0.50	0.31
Rhythmization	Deviation from the model / ms	126.00	125.0	125.4	80.1	152.4	133.0	70.5*	0.80	-0.20
Speed, precision and accuracy	Time / s	33.7	36.0	35.1	4.1	40.6	9.0	41.5*	0.06	-0,61
Speed, precision and accuracy	Number of mistakes / n	8.2	8.3	8.3	3.0	10.6	4.6	1.4	0.16	-0.50
Visual-motor coordination	Time / s	71.2	69.6	70.3	5.3	75.3	9.3	1.5	0.13	-0.54
Visual-motor coordination	Number of mistakes / n	0.3	0.8	0.6	1.0	0.4	0.7	62.5*	0.48	0.28
Spatial orientation	Time / s	55.2	51.3	52.9	6.4	57.0	6.7	1.5	0.14	-0.61
Spatial orientation	Number of mistakes / n	3.0	2.6	2.8	0.9	2.6	2.2	0.2	0.85	0.09

$P \leq 0.05$ – level of statistical significance; no symbol – values of t-Student statistics; * – Mann-Whitney statistics
♦ – top level athletes; ♦♦ – lower level athletes; z – differences normalized with respect to $\bar{x}$ and SD for university students

Differences in means between the group of athletes (n=10) and students turned out to be statistically insignificant. The arrangement of differences in the normalized coordination motor abilities suggests substantially better results in climbers in terms of speed, precision and accuracy of movements (test time, $z = -0.61$, test mistakes, $z = -0.50$), visual and motor coordination (test time, z = –0.54), temporal parameters of kinaesthetic differentiation ($z = -0.80$), spatial orientation (test time, $z = -0.61$), and spatial and dynamic kinaesthetic differentiation (test time, $z = -0{,}66$). However, in three (of 15) comparisons,

Table 3. *Spearman's rank correlation coefficient for the correlation between rock climbing level and coordination abilities studied*

Variable	R	*P*
Kinaesthetic differentiation – spatial parameters	-0.15	0.67
Kinaesthetic differentiation – temporal parameters	0.19	0.58
Spatial and dynamic kinaesthetic differentiation (time)	-0.22	0.52
Spatial and dynamic kinaesthetic differentiation (mistakes)	-0.27	0.44
INDEX - spatial and dynamic kinaesthetic differentiation	-0.19	0.59
Frequency of movements	-0.10	0.76
Visual reaction time	0.10	0.95
Auditory reaction time	-0.06	0.85
Complex reaction time	0.28	0.43
Rhythmization	0.26	0.45
Speed, precision and accuracy (time)	-0.40	0.24
Speed, precision and accuracy (mistakes)	0.03	0.92
INDEX – speed, precision and accuracy	-0.66	0.03*
Visual and motor coordination (time)	0.09	0.78
Visual and motor coordination (mistakes)	0.02	0.94
INDEX – visual-motor coordination	0.00	0.98
Spatial orientation (time)	0.37	0.28
Spatial orientation (mistakes)	0.05	0.87
INDEX – spatial orientation	0.22	0.52

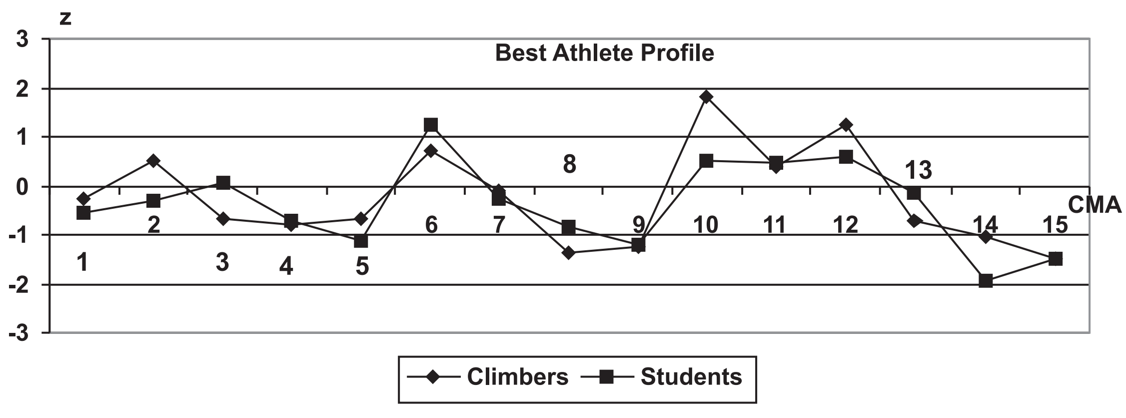
* $P \leq 0.05$ – level of statistical significance

better results were obtained by the students. They showed slightly higher level of: complex reaction time (shorter time), visual-motor coordination (number of mistakes made) and spatial orientation (number of mistakes made). However, the level of normalized differences was low – between 0.09–0.31.

In the group of climbers studied, a statistically significant correlation with rock climbing level was found only in the index of speed, accuracy and precision of movements (see Table 3). In the group of expert climbers, favourable relationships were recorded between effectiveness of climbing and speed, accuracy and precision of movements (test time) and spatial-dynamic kinaesthetic differentiation ability (for the parameters of test time and number of errors). These correlations suggest that the athletes who had achieved better results in climbing performed tests faster and with lower number of errors.

Best athlete profile

Fitness-related profile of the best athlete was developed based on the results obtained for climbers and untrained controls (Fig. 1).



Variables of coordination motor abilities (CMA): 1. Kinaesthetic differentiation – spatial parameters. 2. Kinaesthetic differentiation – temporal parameters. 3. Frequency of movements. 4. Visual reaction time. 5. Auditory reaction time. 6. Complex reaction time. 7. Rhythmization. 8. Speed, precision and accuracy (time). 9. Speed, precision and accuracy (mistakes). 10. Visual and motor coordination (time). 11. Visual and motor coordination (mistakes). 12. Spatial orientation (time). 13. Spatial orientation (mistakes). 14. Spatial and dynamic kinaesthetic differentiation (time). 15. Spatial and dynamic kinaesthetic differentiation (mistakes).
NOTE: higher numerical values for the test No. 3 correspond to better results

Fig. 1. *Coordination profile of the best climber based on on-sight rock climbing performance compared to other climbers and university students*

Compared to other athletes, a “model climber” obtained best scores in tests that evaluated spatial-dynamic kinaesthetic differentiation (z = –1.06 in the test No. 14 and z = –1.47 in the test No. 15). Similarly, the same athlete had better scores during the measurement of speed, accuracy and precision of movements (z = –1.36 in the test 8 and z = –1.23 in the test 9). The best climber had also higher score in the tests that measured visual and auditory reaction time (by z = –0.80 and z = –0.69, respectively, tests 4 and 5). Complex reaction time in this athlete was worse than the mean in the group of climbers (z = 0.70, test 6). Slightly better results of tests that evaluated the ability of kinaesthetic differentiation of spatial parameters and rhythmization pointed to its insignificant advantage (–0.30 and –0.10, tests 1 and 7). Kinaesthetic differentiation of temporal parameters and frequency of movements in the best athlete were poorer compared to other parameters. In addition, the climber obtained worse scores in the visual-motor coordination test (test time and number of mistakes) and spatial orientation test (test time). However, he made fewer mistakes in the spatial orientation test.

Figure 1 also presents a profile of scores of the best climber compared to untrained students. Analysis of the results is consistent with previously observed relationships. Again, compared to students, the “model climber” obtained the best scores in the test that evaluated dynamic-spatial kinaesthetic differentiation ability. The normalized values for this ability were z = –1.95 for the test time and z = –1.49 for the number of mistakes. In the test of accuracy and precision of movements, the best climber had also substantially better scores than the untrained subjects. The normalized values for this ability were z = –0.84 and z = –1.22, respectively. The model climber had better scores in the test that measured time of reaction to visual (z = –0.70) and auditory (z = –1.14) stimuli. Students obtained better scores in complex reaction time. The direction of normalized differences also shows that the untrained controls obtained better scores in terms of visual-motor coordination and spatial orientation. With regard to the latter ability, it should be noted that the best climber, although having worse test time, made fewer mistakes. In general, it can be concluded that the normalized differences between the best athlete and the mean in the group of untrained controls are higher than those obtained compared to rock climbers.

Discussion

The group of climbers studied was characterized by high sport skill level. As mentioned before, the mean score of *on – sight* climbing in the group of climbers was 7c on the French scale. Practitioners and theorists of sport climbing have expressed the views that, apart from energy-related motor skills, one of the most important factors that determine performance on the climbing wall is high level of technical and tactical skills [16,29,30]. Despite statistically insignificant intergroup differences, expert climbers performed better in the most of the coordination abilities tests compared to students. Firstly, this pattern seems to be attributable to a small size of the group of climbers. Secondly, the control group was comprised of the students from university school of physical education, recruited with respect to the level of physical fitness. High level of motor coordination abilities in these students is likely to be developed due to the specific curricula at academic courses at the university. Similar relationships were found by comparison of the results obtained by university students with judo competitors, with the most of the coordination abilities studied being statistically insignificant. Furthermore, statistically significant differences in simple reaction time to visual stimuli and visual-motor coordination were observed in favour of the students [31]. Current research studies are insufficient to provide an unequivocal answer to the interesting questions concerning the effect of congenital and environmental factors on the level of coordination abilities [32].

From the standpoint of recruitment and selection, it seems reasonable to determine the level of key coordination abilities. Rokowski [17] has emphasized that climbing performance might be significantly dependent on the level of spatial orientation.

The results obtained for speed, accuracy and precision of movements seem to be interesting in the context of the present discussion. With respect to the above variable (test time), we found the highest normalized differences in favour of climbers. The index of this ability, including both test time and number of errors, was also statistically significantly correlated with rock climbing results (at the level of R = -0.66). Its correlation with sport skill level in climbing might be attributable to a more or less complex sequence of holds and footholds typical of climbing. In such surroundings, economical and purposeful activities require suitable and harmonious connection of movements of body parts and combining various forms of the movements into specific sequences and sets. In order to climb a route successfully, a climber is forced to use various climbing techniques, such as adopting positions facing in or facing sideways, or climbing overhangs and roofs. Similar to spatial orientation, this ability is largely determined by kinaesthetic and optical information. The basis for high-level motor coordination in climbing is kinaesthetic and visual information. Quality and proper assessment of this information allows for choosing the best movement sequence [17].

Analysis of individual profiles is important for establishment of a coordination-based "champion profile" in climbing. These results should, on the one hand, support the previous analyses, but also make them more specific on the other. We aimed to evaluate the differences between the best climber and other climbers who are also elite athletes in this sport but find it difficult to reach the expected outcomes. Coordination potential of this climber demonstrates that expert climbers should be characterized by superior level of coordination abilities. This athlete showed a high level of speed, accuracy and precision of movements, which was substantially correlated with climbing performance. The best climber was characterized by a very high level of the ability of kinaesthetic differentiation of movements (spatial-dynamic parameters (time and errors). We realize the necessity of further research into the importance of individual coordination abilities in rock climbing in order to verify the obtained results.

Conclusions

The results obtained in the study lead to the following conclusions:

1. Speed, precision and accuracy of movements and ability of kinaesthetic differentiation of spatial and dynamic parameters are likely to be the most important component to affect climbing quality.
2. Analysis of a coordination profile of the best climber indicates that his level of coordination abilities might determine a success in sport.
3. The control group of students from a university school of physical education demonstrated proper level of coordination skills, which suggest proper selection of candidates for physical education teachers.

Declaration of interest

The authors report no conflicts of interest.

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B – Data Collection
C – Statistical Analysis
D – Data Interpretation
E – Manuscript Preparation
F – Literature Search
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