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The role of kinaesthetic feedback in goal-directed movements

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The purpose of this study was to investigate the role of kinaesthetic feedback in the control of goal-directed movements. The subjects were qualified basketball and handball players compared to weightlifters as controls. The body measures and the general motor tests verified fit physical condition of the subjects, and detected no sign that would disturb the execution of special motor tests. The special motor tests were free-throw shootings with basketball to the basket, free shootings with handball to a rectangular frame, zigzag dribbling with basketball to 14 m among traffic cones 2 m apart, and stopping at a mark after running to 10 m. These tests were performed both with open eyes and closed eyes. The results of all special motor tests decreased significantly in the lack of visual information. Furthermore, in contrast to the significantly different results obtained from the three different groups with open eyes, these groups produced equally minor results with closed eyes. It is concluded that the practice of goal-directed movement, learned under visual guidance, does not make the kinaesthetic feedback able to compensate the lack of visual input.

Keywords: basketball, feedback, feedforward, handball, kinaesthesia, motor tests, physical performance

The control of goal-directed movements is the result of an interaction between feedforward and feedback mechanisms (Fig. 1). The feedforward controls the execution of the movement from a starting point towards a given target. The adjustment of the body position to the directional parameter involves feedback mechanisms.

Both feedforward and feedback mechanisms are based on visual, vestibular and kinaesthetic sensations, so these signals are important for maintaining balance and controlling movements (8, 10, 11). However, it is not entirely clear whether these sensory inputs are used in a hierarchical way, for example, visual priority over

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kinaesthetic input, or all three inputs are used parallel (6). For the latter case it was suggested that after exclusion of one of the three systems the other two are able to compensate completely.

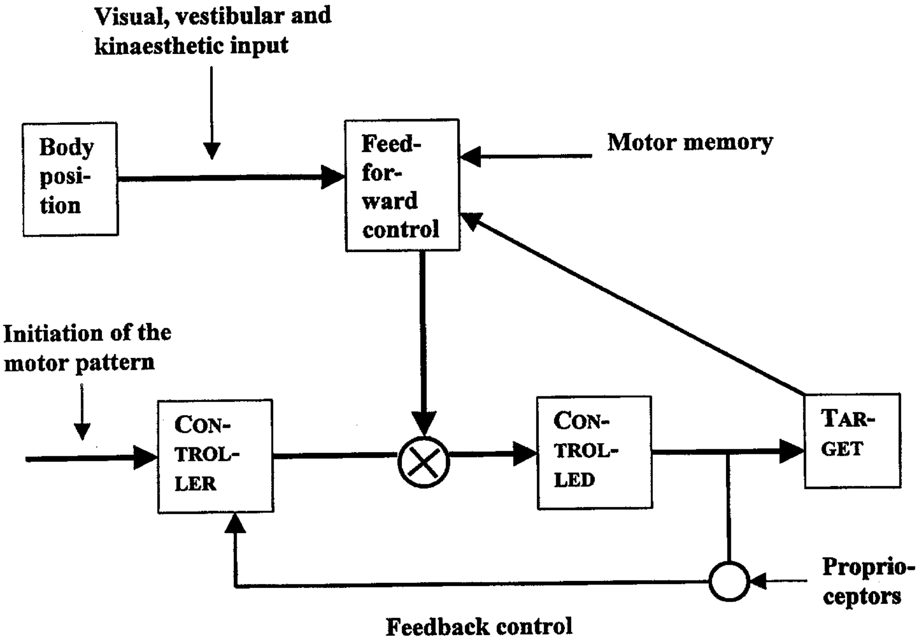

Fig. 1. Schema of the feedforward and feedback control of goal-directed movement

The kinaesthetic afferent signals arise from three main groups of peripheral receptors, namely, i) mechanoreceptors located in joint capsules, ii) proprioceptors of the muscle, and iii) cutaneous mechanoreceptors (10). These sensations assist in adjusting the appropriate parameters (strength, velocity, range of motion, etc.) to the movements, and to control movement sequences (5). For example a healthy person is able to walk on stairs, both upstairs and downstairs, without beholding every step. The kinaesthetic information contributes both to increase in the physical performance and to prevent injuries.

The purpose of this study was to determine the efficacy of kinaesthetic feedback in the control of goal-directed movements. We choose free throw shooting for testing. Shooting is the most important skill in basketball and handball. The subjects were professional basketball and handball players compared to weightlifters, in order to verify the assumption that the practice enhances the kinaesthetic control of motor skills.

Materials and Methods

The subjects were professional athletes: 13 basketball players (21.6±2 yr.), 16 handball players (21.6±2.6 yr.), and 7 weightlifters (21±6 yr.) as controls. All subjects were participating in the examinations voluntarily with written consent. The Ethics Committee of the Medical School of University of Pécs permitted the study.

Anthropometrical measurements

Body height, circumferences of upper arms, and chest at the level of xiphoid process of the sternum were taken with the individual standing erect on a smooth surface. For body weights measurement the subject, wearing sports clothing, was standing in the centre of the scale.

General motor testing

General motor testing consisted of Flamingo (one-legged) balance test, handgrip dynamometry, flexibility test, bent arm hanging, and vertical jump from a standing start. For the Flamingo balance test the subject was balancing on one shoeless leg on a 50-cm long, 4 cm high and 3 cm wide wood beam. The number of attempts needed to keep in balance on the beam for one whole minute was recorded. Handgrip strength was measured by Jamar hydraulic hand dynamometer. Flexibility was measured by a lower back and rear thigh test. The subject was standing on a footstool with feet together and knees straight. The task was to bend forward to reach for the maximum bending, and maintaining this position for 2 sec. The maximum distance between the surface of the footstool (0 level) and the middle finger tip was measured, and expressed by negative numbers above the 0 level, and positive numbers below the 0 level. The result is given in cm. The arm and shoulder muscular endurance was measured by maintaining a bent arm position while hanging from a bar. The result is given in sec. The explosive strength was measured by vertical jump test. First the reach height was measured when the subject was standing erect on a smooth surface and lifting up his arm. Then the vertical jump was tested. The difference in distance between the reach height and the jump height is the score. The result is given in cm. We used a simple test of coordination, the finger-nose test, in which the subject was asked to touch his nose after withdrawal of vision.

The special tests

The special tests were:

- 10 free-throw shootings with basketball to the basket from the distance of 4.8 m performed, first, with open eyes then with closed eyes,
- 10 free shootings with handball to a rectangular frame of 60 cm all sides, from the distance of 7 m performed, first, with open eyes then with closed eyes,
- zigzag dribbling the basketball to 14 m among traffic cones 2 m apart,

– rapid stopping at the mark of 10 m distant performed, first, with open eyes then with closed eyes. At the end of running the deviation from the straight line to right or to left side is given in cm. The stopping before the mark is expressed by negative numbers and by positive numbers if the subject passed the mark (Fig. 2).

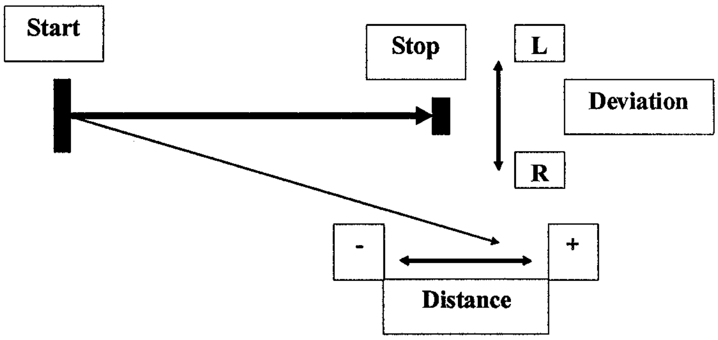

Fig. 2. Sketch of the test

It was carefully controlled in all tests that the body position at the start with closed eyes was similar to that with open eyes.

Statistical analysis

For statistical analysis descriptive statistics and Student's *t*-tests were used.

Results

The data obtained from the anthropometrical measurements showed no asymmetry between the right and the left sides of the body. Some body measures are shown in the Table I.

The general motor tests revealed different flexibility, static and dynamic forces, and balancing for the three groups. However, the differences in flexibility, vertical jumping and handgrip results were not significant statistically. The results of the Flamingo test and that of the bent arm hanging from the bar were significantly different between the basketball players and the weightlifters. The results of the general motor tests are shown in Table II.

The times for zigzag dribbling the basketball to 14 m among traffic cones 2 m apart were significantly different among the three groups (Table II). The other specific tests showed significant differences among the three groups when the tests were performed with open eyes. However, no statistically significant differences were obtained when the special tests were completed in the absence of visual input. The results of 10 free-throw shootings with basketball to the basket are shown in the Figure 3, and that of the 10 free shootings with handball to the rectangular frame are shown in Figure 4. It is interesting that no significant correlation was found between the results obtained from trials with open eyes and closed eyes.

Table I

Body measures (mean ± SE) of the subjects

Groups	Heights (cm)	BMI*	Body fat (%)	Waist/hip ratio
Basketball	196±1.9	22.5±1.5	11±4	0.93±0.04
Handball	185±1.7	24±1.9	11.2±3.4	0.94±0.02
Weightlifter	176.8±2.4	27.5±4.8	15.9±8.7	0.94±0.02

* BMI=body mass index

Table II

Results of the motor tests indicating the physical fitness of the subjects

Groups	Flamingo test (attempts)	Flexibility (cm)	Hanging (sec)	Jumping (cm)	Handgrip (right) (kg)	Zigzag dribbling (sec)
Basketball	11±5.1*	7.7±10.8	50.9±12*	57.8±5.3	50.5±9.8	7.9±0.15*
Handball	12±5	8.9±7.7	42.7±14.9	59.2±4.4	56±9	8.6±0.17*
Weightlifter	16±7.7*	12.6±2.9	38.7±9.9*	60±4.6	57±9	10.4±0.4*
P*	P<0.05	NS	P<0.05	NS	NS	P<0.01

* Significance of the difference between the groups marked by *

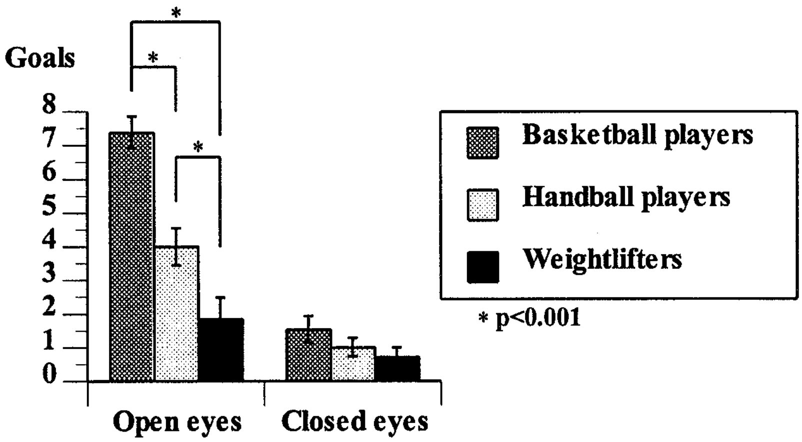

Fig. 3. Results (mean ± SE) of free-throw shooting with basketball

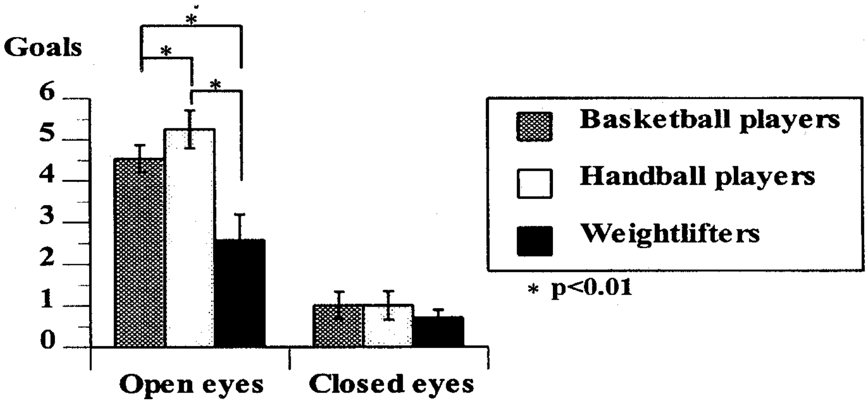

Fig. 4. Results (mean ± SE) of free shooting with handball

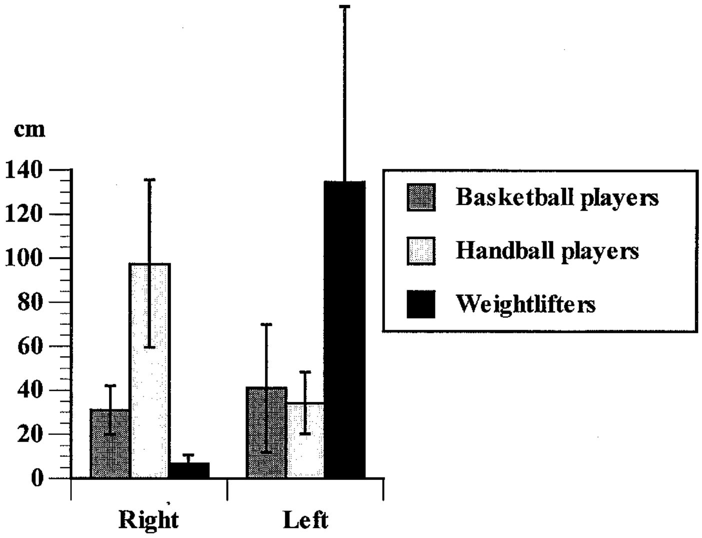

Fig. 5. Deviation from the end of running to 10 m (mean ± SE)

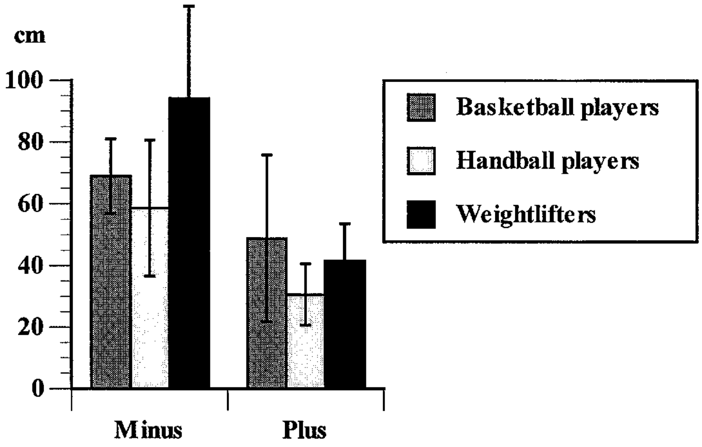

Fig. 6. Distance between the place of stopping and the target of 10 m running (mean ± SE)

Table III

Number of subjects producing different deviations and distances from the target after running with closed eyes

Groups	Deviation from the line		Distance from the target	
	Right	Left	Minus	Plus
Basketball players	7	6	8	5
Handball players	9	7	9	7
Weightlifters	3	4	4	3

The lateral deviation from the straight line at the end of running with closed eyes to 10-m distance was unexpectedly big into both directions (Fig. 5). Similarly, the subjects stopped much before or behind the mark (Fig. 6). The numbers of subjects performing the different results are shown in Table III. The individual results were very varying in all directions, and in all groups. No statistically significant differences were found between the results of the three groups.

All subjects performed correctly the simple finger-nose test.

Discussion

The results summarized in Tables I and II show no component that would disturb the execution of the special motor tests.

To examine whether motor preparation process, i.e. the appropriate body position and motor memory, is able to compensate the lack of visual guidance in carrying out the goal-directed movement, two types of tests were used: i) the execution of a complex movement, and, ii) the maintaining the direction of a continuous running, and stopping at a given mark.

i). Free throw shooting was used as motor test. Shooting is the most important skill in basketball and handball. During training the shooter needs to learn how it feels to do the correct action. This feeling comes from the appropriate body position (balance, holding the ball, etc.), and from the successful shooting motion. The shooting motion is a complex pattern of movements from the legs to the wrist that precedes the sending of the ball towards the target. Thus to learn shooting needs a powerful kinaesthetic feedback correction. The role of kinaesthetic feedback in motor preparation was supported by recent studies (3, 4, 7). The direction of shooting motion is guided by visual input. The training of the successful shooting strengthens the motor memory. This way of thinking led to the question that whether a well-trained player is able to perform successful shooting in the lack of visual guidance?

The results obtained with open eyes are distinctive for the appropriate groups; the well-trained basketball and handball players produced significantly better results than the weightlifters. In contrast to these expected results, no significant differences were obtained from the shootings with closed eyes. In the lack of the visual input the learned motor patterns, built in the brain, remained unchanged. Because the position of the head is similar to that during shooting with open eyes, also the vestibular afferent activity did not change significantly. In a series of comparing pointing movements it was found that systemic errors decreased if the subjects were allowed to see their hand before movement onset (13). In our experiments the subjects performed the same series of movements just before testing with closed eyes. So, the starting position was similar in both conditions. The muscle spindle receptors are sensitive to minute changes in muscle length; therefore, primarily the proprioceptors are controlling the movements in the absence of visual input (11). However, the present results show clearly that the kinaesthetic control is insufficient to compensate completely the lack of visual input. A possible explanation for this insufficiency is that the visual input was predominant over the kinaesthetic information during skill development. Thus the cue stimulus to guide the motor memory is visual. This idea is supported by the "practice hypothesis" that utilization of kinaesthetic information enhances through practice during motor learning (2, 12). However, the above results failed to support the idea that a goal-directed movement developed under visual guidance may be executed precisely in the lack of visual input.

ii). The maintenance of the direction of movements and stopping at a target is an important manifestation of the neural control. As it was expected, no disturbances occurred if the movements were performed with open eyes. However, in the lack of the visual input both the maintenance of the direction of movements, and the stopping was disturbed. It is important to emphasize that i) big individual differences were found, ii) there were no preferences neither in the direction (right side versus left side), nor in the distance (before versus behind the target), and, iii) no statistically significant differences were obtained from the three groups. It is difficult to explain these results. An anthropometrical or functional asymmetry would give an acceptable reason for these alterations. However, neither the anthropometrical measurements, nor the general motor tests revealed asymmetries between the right and the left sides of the body. Also an uncertainty in motor coordination might cause lateral deviation and erroneous estimation of the distance. However, the motor coordination measured by the time for zigzag dribbling the basketball to 14 m among traffic cones 2 m apart showed no difficulties. Also the simple finger-nose test was performed correctly. It is possible that the errors originate from the visual dominance over kinaesthetic information during acquisition of motor skills. Therefore, the kinaesthetic estimation of the direction and distance is insufficient to direct the motor memory in the absence of visual input.

The above results indicate that the increase in efficiency of kinaesthetic feedback in the control of goal-directed movements needs enhancement of kinaesthetic sensations during skill development.

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