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THE ROLE OF VISUAL INPUT DURING ROTATION: THE CASE OF DISCUS THROWING

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Abstract. In order to investigate the contribution of visual information in the control of a skill involving rotation, ten experienced discus throwers performed throws under full vision, peripheral vision only, central vision only, and blindly. Throwing performance was significantly inferior when only central vision was available as compared to the full and peripheral vision conditions (38.55±3.14 m vs. 40.24±3.63 m and 40.10±3.78 m respectively; p=0.002). No differences between the central vision and no vision condition occurred (38.55±3.14 m and 39.32±3.40 m respectively; p>0.05). Better performance in the full and peripheral vision conditions as compared to central vision only underlines the importance of peripheral information in the control of ego-rotation, and provides support for two functionally different visual pathways. The lack of performance differences between full vision, peripheral vision, and no vision indicates that experts may have learned to rely on other, non-visual information sources during the acquisition process or that they have learned to quickly adapt to changing informational constraints. ***(Biol.Sport 22:53-66, 2005)***

Key words: Discus throwing - Visual information - Central vision - Peripheral vision

Introduction

In recent years, the contribution of visual information in the control of movements has received considerable attention, in daily-life activities as well as in sport skills [4,6,10]. Part of the debate has focused on the relative contribution of information from the central and peripheral visual field to the control of ego motion. Laurent *et al.* [3,15] demonstrated that peripheral vision is essential for the

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control of one's speed during walking and braking behavior. Participants in Laurent's study tended to adapt their walking velocity to the speed of the information flow in the peripheral visual field, even if this information was erroneous. In an experiment in which participants had to brake before an obstacle, braking was more efficient in the peripheral vision condition than under central vision only. Eves [9] showed a decrease in performance in long jumping when peripheral vision was removed. Apart from its role in controlling ego motion, peripheral vision can also play a part by providing information about the kinematics of limb movement, although this effect seems to be task and expertise dependent [1,10,19].

While the role of peripheral vision in linear translations is well documented, its role in the control of rotations during sport activities is less clear. Moving along a linear path, like in long jumping or javelin throwing, results in the generation of a horizontal lamellar flow in the peripheral field and an expansion flow in the central visual field. In contrast, rotations of the body cause a lamellar flow in the central field as well as in the peripheral field. Studies of movement perception have indeed shown that the central as well as the peripheral field can generate the perception of rotation [2]. On the one hand, the horizontal lamellar flow might inform the athlete on his speed of rotation: the higher his speed, the larger the flow vectors. On the other hand, the flow may help to maintain balance during rotation: a deviation from the horizontal path of the flow vectors informs the athlete that the head is going up or down. There is a theoretical possibility that during rotations, the information from the central and peripheral visual field are equivalent, and that the differences found in linear sport activities do not occur in rotation activities.

However, very scant information on the role of central and peripheral vision during rotation is available in tasks pertinent to sport activities. One of the exceptions is the summary article of Graybiel, Jokl and Trapp [11] in which they report experiments with discus and hammer throwers performing under normal and restricted visual conditions. They reported that performance in hammer throwing decreased from full vision over central vision only to a total elimination of vision. Similarly, discus throwing performance deteriorated from full vision over peripheral vision only to central vision only. Graybiel *et al.* also mention that throwing with central vision only even leads to worse performance than throwing blindly, although they do not provide data to strengthen this statement. Unfortunately, the scant information on methods and results provided by Graybiel *et al.* make their conclusions questionable, and make it opportune to replicate the study with expert discus throwers, with the addition of a no vision condition in order to estimate the contribution of non-visual information sources.

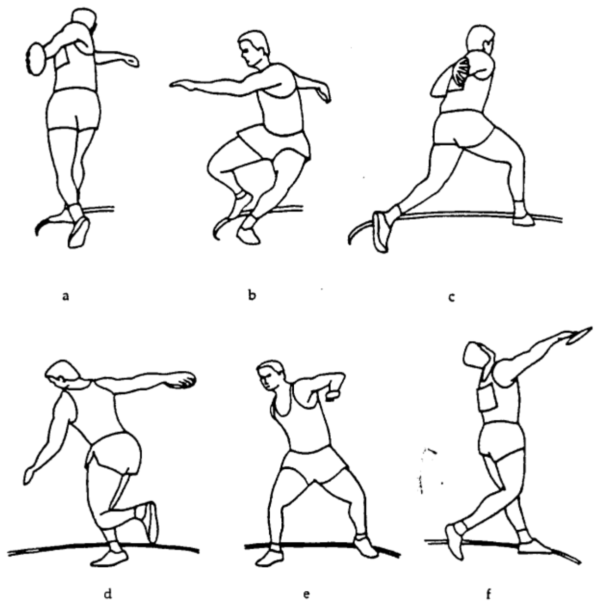

Fig. 1
The five phases in discus throwing: preparation (a-b), entry (b-c), airborne (c-d), transition (d-e), and delivery phase (e-f). Adapted from Hay and Yu [13]

In skilled discus throwing (Fig. 1), the thrower performs one and a half turn before releasing the discus. Most authors subdivide the discus throw in five phases as shown in Fig. 1 [5,13,17]. The aim of the turning technique is a) to give the discus an initial velocity prior to the actual throwing movement, and b) to obtain a lead of the legs and hips over the throwing arm, so that the pre-tension of the shoulder and arm musculature can be used to maximize the release velocity of the discus.

The aim of this experiment was to assess the contribution of visual information, and information from the peripheral and central visual field in particular, to the control of a skilled rotation task like discus throwing in experts. Therefore we investigate discus throwing under four visual conditions: full vision, central vision, peripheral vision, and no vision. In line with Graybiel *et al.* [11] suggestion, it is hypothesized that a decay in performance will occur from throwing with normal vision and peripheral vision only to central vision only and no vision. The occurrence of differences between conditions would plead for a significant role of visual input during discus throwing, apart from other on-line information sources for the control of ego rotation.

Material and Methods

Participants: Ten experienced discus throwers (seven males and three females) volunteered to participate in this study after giving their informed consent. They had between 4 and 15 years of specific discus training and competed at national level. Their physical and training characteristics are given in Table 1. None of them had previous experience with throwing under degraded visual conditions, i.e. without central or peripheral vision or without vision. All participants were right-handed throwers and reported normal or corrected-to-normal vision.

Table 1
Mean (M), standard deviation (SD), and range of physical and training characteristics

	M	SD	Range
Age (yr)	21.4	4.9	16.5-32.3
Height (cm)	187.1	9.9	1.67-2.01
Weight (kg)	88.5	15.0	60-109
Experience (yr)	7.7	3.7	4-15
Personal Best (m)	47.01	5.50	40.29-57.68
Number of Throws/Year	3012	1736	1300-6000

Apparatus: All throws were performed from a discus ring of 2.50 m diameter within a safety cage into a 40° sector as prescribed by the rules of the International Amateur Athletic Federation [14]. A 25 Hz Panasonic video camera was placed at three meters to the right from the center of the circle at a height of two meters to register the position of the feet. To this end a 0.05 x 0.05 m grid was drawn on the ring surface, and the tip of the feet of the throwers were marked with contrasting tape. A 200 Hz NAC camera was put up perpendicularly to the middle of the throwing sector so that the movements of the thrower and the first five meters of the flight of the discus could be monitored. Before each session, a 2.5 x 2.5 m frame was filmed in the plane of delivery for calibration purposes. From the landing spot of the discus, the distance (up to 0.01 m) and the discus trajectory (up to 1°) was measured [1].

Throws were executed under four visual conditions: full vision (FV), peripheral vision only (PV), central vision only (CV), and no vision (NV). To this end, lightweight goggles were used for the restriction of visual input. In order to eliminate the effect of wearing goggles, transparent goggles were used in the FV condition. To eliminate central vision, the front of the goggles was covered with black adhesive tape, leaving an average lateral peripheral visual field of 25°. In the CV condition, 2 cm diameter tubes were glued on the front, while the rest of the goggles were covered. This resulted in a central visual field of about 15°. These visual restrictions are comparable to those used in other studies [3,10]. In the NV condition, opaque goggles were used.

Procedure: The standard warming-up procedure consisted of jogging and stretching during 20 minutes, followed by three throws without visual restriction. Before the actual test throws, they were allowed to wear the different glasses and to walk around to get used to the specific visual conditions, however without throwing.

Participants performed ten throws at maximal intensity under each visual condition in a fully randomized order. This order, in which the same visual condition did not occur on more than two trials in a row, was the same for all participants. The distance thrown was the only source of extrinsic feedback that was given. The total volume of 40 test throws was less than the amount of throws during a regular training session, so that potential fatigue effects would not interfere with performance. In addition, the experiment was done with several throwers in one session to provide them with a few minutes rest between throws. The starting position was identical for all throws of the same participant, meaning that both feet were at the same position on the grid in the circle. Participants put on the goggles after they adopted this position in the ring. Participants threw with a weight varying between subjects from 1 kg (3 females) over 1.75 kg (2 male juniors) to 2 kg (5 male seniors) corresponding to the national prescriptions for their sex and age. After the test, participants wrote down their subjective perceptions of throwing under the different visual conditions. No formal

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[1]Under specific wind conditions, the discus may tilt during the flight if it is not delivered correctly. Tilting causes a significant deviation from the linear path during the flight, and mainly occurs in novice throwers. During the experiment, an observer in the throwing area visually controlled for tilting. However, none of the trials had to be repeated because of tilting.

questionnaire or interview technique was used for this purpose. The answers were evaluated qualitatively.

Dependent variables and statistical design: Distance of each throw was measured with an accuracy of 1 cm from the inner border of the ring to the nearest landing mark in the throwing area. The discus trajectory, which is important to avoid fouling, was measured in degrees relative to the right border of the official 40° landing sector. Next to these performance variables, the following release parameters were measured. Release angle (in °) and resultant release velocity (in m/s) were calculated from the first 150 ms of the path of the discus. These two variables were calculated from the 2D-images of the camera perpendicular to the midline of the throwing area, and the discus trajectory. Release height (in m) was defined as the vertical distance between ground level and the center of the discus at the time of release. Temporal parameters of the throw were the total duration, and the duration of the five phases. These were determined from the high-speed images at an accuracy of 5 ms. Finally, two spatial variables were calculated. First, the distance between the feet at the start of the delivery is important because the leg and trunk power can only be transferred to the throwing arm and discus in this phase if both feet are well positioned relative to each other. A too wide or too small stance is detrimental for throwing performance. A too wide stance results in difficulty in actively pushing the hips to the front of the circle, while a small stance will prevent an optimal pre-tension of the trunk muscles and make the path of the discus shorter [20]. Second, the orientation of the axis between the feet with respect to the midline of the throwing sector during the delivery is important to avoid the discus hitting the cage or landing outside the sector.

Next to these variables, the respective intra-subject Standard Deviation (SD) was calculated to test to what extent performance consistency is affected by changes in visual input. Data was analyzed with a one-factor (visual condition with four levels: FV, PV, CV, and NV) repeated measures ANOVA with a Huynh-Feldt adjustment to control for violations of the sphericity assumption in ANOVAs. Tukey's Honestly Significant Difference (HSD) post hoc test was used for further analysis ($p<0.05$).

Results

Preliminary remarks: In order to exclude the possibility of fatigue effects, a 2 (blocks of trials: 1-20 and 21-40) x 10 (participants) ANOVA with repeated measures on the first factor was performed. No differences in performance between the first and the second block occurred ($F_{1,9}=2.053$, $p>0.05$). Post hoc analysis revealed that all participants performed equally in the first and second block (all p-values >0.05).

A large discrepancy between the participants' personal bests and their performance in the unrestricted visual condition is obvious from Tables 1 and 2. Next to the impossibility to replicate a record throw 40 times in a row, this discrepancy is probably due to the absence of comfortably warm weather and a head wind, two factors that are doubtlessly beneficial for expert discus throwers [5].

Subjective perception by the participants: All participants spontaneously reported that throwing with only central vision resulted in the greatest amount of confusion, while performing with peripheral vision only was not perceived as being more difficult than under full vision. Throwing blindly was reported to be more comfortable than throwing with central vision only. Five subjects specifically mentioned timing problems in the central vision condition.

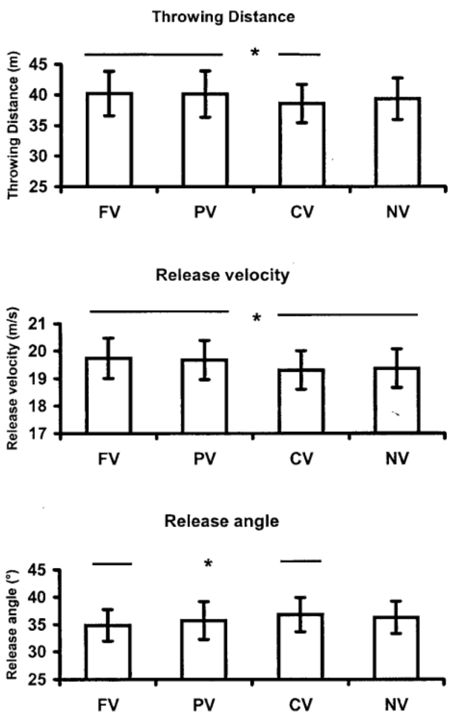

Fig. 2
Means and standard deviations of throwing distance (top), release velocity (middle), and release angle (bottom) of the discus in the four visual conditions (FV: full vision, PV: peripheral vision, CV: central vision, NV: no vision)

Table 2
Performance variables, release parameters, temporal and spatial parameters under four visual conditions

	Condition							
	Full vision		Peripheral vision		Central vision		No vision	
	M	SD	M	SD	M	SD	M	SD
Distance (m)	40.24	3.63	40.10	3.78	38.55	3.14	39.32	3.40
Throwing direction (°)*	13.83	4.98	13.02	5.85	12.94	10.33	13.29	8.23
Release velocity (m/s)	19.74	0.73	19.67	0.71	19.30	0.70	19.36	0.70
Release angle (°)	34.85	2.89	35.73	3.45	36.78	3.11	36.26	2.94
Release height (m)	1.45	0.13	1.45	0.13	1.46	0.12	1.45	0.13
Total time (ms)	1521	127	1534	132	1536	135	1536	128
Preparation (ms)	541	98	550	98	539	99	547	94
Entry (ms)	453	86	453	78	459	82	458	76
Airborne (ms)	83	35	82	36	76	36	77	40
Transition (ms)	238	49	242	46	255	47	249	48
Delivery (ms)	205	22	207	25	207	26	205	25
Distance between feet at start of delivery (m)	1.10	0.11	1.10	0.11	1.11	0.09	1.09	0.10
Orientation of axis between feet during delivery (°)**	16.3	11.1	14.5	10.2	15.8	9.7	13.6	11.7

*With respect to the right border of the throwing sector. A positive value represents landing at the left side of this line;
**With respect to the midline of the throwing sector. A positive value indicates an orientation towards the left side of this line

Performance variables: A significant effect of visual condition on distance was found ($F_{3,27}$=6.508, p=0.002). Post hoc revealed that performance in CV was worse than in the FV and PV conditions (p<0.05), but not different from the NV condition. Although all ten participants threw farther blindly than with central vision only (0.77 m on average, ranging from 0.05-2.57 m), this tendency failed to reach statistical significance. Performance under FV, NV, and PV did not differ from each other. No effect on the within-subject variability was found ($F_{3,27}$=0.129, ns). Discus trajectory was not affected by the visual manipulations, nor was the within-subject variability in discus trajectory ($F_{3,27}$=0.062, ns and $F_{3,27}$=0.309, ns, respectively).

Release variables: Release velocity was higher in the FV and PV conditions than in the CV and NV conditions ($F_{3,27}$=9.648, p<0.001, post hoc <0.05). Visual manipulation significantly affected release angle ($F_{3,27}$=3.932, p<0.05), and post hoc analysis showed that this angle was larger in the CV condition than in the FV condition. No other differences occurred. The type of visual information did not significantly affect release height ($F_{3,27}$=0.144, ns). For these three release variables, no significant differences in within-subject variability between the four conditions were found (F-values of 1.164, 1.567, and 0.732 for release velocity, angle and height, respectively).

Temporal variables: The total duration of the throw was not affected by the visual conditions ($F_{3,27}$=2.961, ns). However, the transition phase took significantly more time under CV only than under FV and PV, while no difference between NV and CV was found ($F_{3,27}$=8.100, p=0.001, post-hoc <0.05). Manipulation of visual information did not influence the duration of the other four phases (all F-values <3.000, ns). Duration of the entry phase was more variable under CV than under FV and PV, while no difference between NV and CV occurred ($F_{3,27}$=3.310, p<0.05, post-hoc <0.05). Similarly, the duration of the airborne phase was less consistent in CV as compared to the FV and PV conditions, while no difference between NV and CV was found ($F_{3,27}$=3.002, P<0.05, post-hoc <0.05).

Spatial variables: The distance between the feet during the delivery phase was not affected by visual restriction ($F_{3,27}$=0.751, ns). The orientation of the axis between left and right foot under the four conditions was invariant with respect to the centerline of the landing sector ($F_{3,27}$=1.194, ns). No difference in variability for these spatial variables was found ($F_{3,27}$=0.377 and $F_{3,27}$=0.606 for distance and orientation, respectively).

Discussion

The aim of this study was to investigate the role of visual input in a discrete rotation skill like discus throwing. Distance thrown decreased under central vision as compared to full and peripheral vision, but no differences between central vision and no vision occurred. Decrease in performance was accompanied by lower release velocity and higher release angle. A disturbance in temporal characteristics of the throw under central vision as compared to full and peripheral vision was found, while spatial execution was not affected by visual manipulations.

The decrease in throwing distance in central vision as compared to full and peripheral vision is partly due to a higher release angle and above all to a lower release velocity, the most determining factor in all throwing events [5]. The non-optimal release angle and velocity are very likely the result of the same kinematic change, namely the increased temporal interval between the right and left foot contact in the transition phase of the throw. A late placing of the left foot (for the right-handed thrower) will jeopardize the optimal action of the right leg [8]. This temporal disturbance will have two major consequences: On the one hand, the throwing arm will show a tendency to lower, leading to throwing from low to high and thus causing an increased and less optimal release angle. On the other hand, the pre-tension that has been built up during the first turn will be partially lost, leading to a shorter acceleration path of the discus and consequently a lower release velocity. The increased temporal variability during the entry and airborne phase also documents that the absence of peripheral information leads to a disturbance in the temporal pattern of the throw. It can be concluded that the temporal structure of the movement is altered under central vision only as compared to full and peripheral vision, leading to a decrease in performance. The subjective perceptions of our participants are in line with such an explanation.

The decrease in performance in skilled discus throwers when only central vision is available confirms the literature findings. The detrimental effect of removing peripheral vision has already been shown for the control of linear movement such as in javelin throwing, long jumping, walking, or braking in front of an obstacle [3,9,10,15]. Why is central vision only not efficient in this particular task involving rotation, as already suggested by Graybiel *et al.* [11]. A first reason might be that the limited visual field did not allow visual information on the position of the limbs during the throw. Eves *et al.* [10] found that, in novice javelin throwers, performance decreased in the absence of peripheral vision presumably because of the lack of visual information on the limbs and the javelin. However, there is evidence that during the learning process, other information sources like proprioception can take the place of visual information on position and movement of the limbs in experts [6,19]. The finding that performance without vision was not different from throwing under normal vision in our study, and the lack of spatial differences in foot positioning, corroborates this thesis. Expert discus throwers apparently do not need visual information for a correct positioning of their feet. A second explanation of poorer performance under central vision only might be that the functional significance of information from the central and peripheral field is not equal, in spite of the fact that both produce a lamellar visual flow during rotation. There is evidence for the existence of two separate channels for the processing of visual information, anatomically as well as functionally [7,16]. According to this approach, information from the central visual field mainly deals with identification of objects and situations. Processing of information via this channel occurs rather slowly and consciously. The peripheral visual field has a high sensitivity for dynamic information, and is featured by a relatively unconscious and fast processing of information [16]. Taking into account that our athletes rotated at an average speed of about 360°/s, it might be that there is simply no time to process the information from the central visual field in a conscious way, and that information from the periphery is more suitable in this task. This thesis might explain the temporal differences between throwing under central vision as compared to throwing with full or peripheral vision, as well as the subjective feelings of discomfort in the central vision condition.

As an intermediate conclusion, our data tend to show that peripheral vision is beneficial for maximal performance. However, although the reported differences between visual conditions are consistent and significant, we must admit that these differences are rather small in absolute terms. For example, throwing distance decreases with less than 5% when comparing the full vision and the central vision condition. In addition, throwing performance did not significantly decrease when throwing blindly. Both observations strongly indicate that other information sources like kinesthetic or vestibular cues are almost equally used in all visual conditions, or that our participants switched from one or more information sources to another depending on the availability and quality of the information. The human operating system is indeed very adaptive to varying informational constraints, as was for example shown in ball catching studies [21]. During regular training, discus throwers have access to these non-visual information sources, and our results indicate that they are able to effectively use these sources in the absence of vision. Another potential explanation for the lack of more pronounced differences is that during the acquisition process, the importance of afferent information gradually decreases as expert throwers develop stable motor programs for the control of the throw [18]. Although this view is often criticized in motor control literature [12], and although the present experiment was not explicitly designed to test this thesis, it remains a possibility than cannot be ruled out yet.

The practical application is that non-visual information might help the thrower when the visual conditions are not optimal, for example when throwing in the evening or in misty conditions. On the other hand, throwing blindly can also be used as a test to evaluate the stability of the thrower's technique.

Elite throwers often use focal points in discrete parts of the throw in order to increase separation of the upper and lower body. For example, during the transition phase they may focus on a point at the rear of the circle during a short time. This will slow down the rotation of the upper body relative to the lower body, so that a more pronounced pretension of the trunk and shoulder muscles is obtained before the delivery phase. Obviously, central vision is essential for the perception of these focal points. Although the results of the present study show that performance under peripheral vision only – when the focal points technique cannot be used – is superior to that under central vision alone, this is not necessarily in contradiction. Central vision may be necessary for focusing on a certain point at a discrete moment during the throw, but may be insufficient for the continuous monitoring of the whole throwing sequence. Apparently the advantage of using focal points in the central vision condition does not counterbalance the loss of peripheral vision in this condition.

In sum, our data underline the importance of peripheral vision for the control of ego motion during rotation, and more specifically for the temporal structure of skilled discus throwing as compared to central vision. However, reasonable good performance was also obtained in visually degraded conditions. The results of this study support the position that skilled behaviour stems from the flexible use of several information sources depending on their availability and usefulness, rather than being the result of one specific coupling between information and action.

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