Control of locomotion in expert gymnasts in the absence of vision

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The main aim of this study was to determine how gymnasts are affected by the removal of vision when executing simple moves. A secondary aim was to establish whether crucial sensory cues exist for blindfolded gymnasts. Eight expert gymnasts were asked to maintain a straight displacement during three types of blindfolded locomotion: walking, steering a wheelchair and verbally ordering a second person pushing their wheelchair. In the first two conditions, active displacement made proprioceptive cues available to update the body trajectory. In the last condition, however, proprioceptive cues were greatly reduced, since the gymnasts displaced passively. The performance of the gymnasts was compared to that of eight experts in other non-gymnastic sports (control group). The results showed that the participants veered in all conditions. However, except in the verbal condition, the gymnasts departed less from linearity than the controls. We conclude that: (1) even for a simple motor task, gymnasts’ performance is altered by eliminating vision; (2) compared with other sportsmen and women, gymnasts are better able to deal with the absence of vision when proprioceptive cues are available. These findings suggest two possible explanations: (1) gymnasts are more able to ‘pick up’ crucial information and (2) a gymnast’s proprioceptive system is more sensitive.

Keywords: blindfolded locomotion, expertise, gymnastics, sensory system, veering.

Introduction

Performing complex motor skills, such as those involved in high-performance sports, places great demands on the sensory and motor systems. Surprisingly, although several studies have dealt with the properties of the expert athlete’s motor system, study of the properties of the sensory system is relatively recent. Experiments conducted on experts’ sensory systems have led to ambiguous conclusions. A first body of literature suggests that experts in sports, owing to structural differences in their perceptual system, are more efficient. Vedyaev et al. (1975) analysed the differential sensitivity of the kinaesthetic and visual systems of athletes in various sports. They found that the sensitivity of these systems depends greatly upon the sport in question. For example, Kioumourtzoglou et al. (1998) reported that experts in ‘open-skill’ sports (e.g. basketball, volleyball and water polo) display better visual performances than novices. In other sports, such as Tai Chi Chuan, kinaesthetic perception improves with expertise (Jacobson et al., 1997). A second body of literature suggests the main characteristics of experts in sports do not necessarily lie in improved peripheral and/or central parts of their perceptual systems. This has recently been confirmed for the visual performance of clay target shooters, where skilled and novice clay shooters performed similarly (Abernethy and Neal, 1999). In fact, it has been claimed that an athlete’s sensory system may be more able to ‘pick up’ crucial information via the perceptual system. For instance, using a technique of film display with squash players, Abernethy (1990) concluded that ‘the limiting factor in the perceptual performance of the novices is not an appropriate search strategy but rather an inability to make full use of the information available’ (for soccer, see Williams and Davids, 1998). In particular, this would explain why expert athletes can anticipate motor adjustments earlier.
than novices. However, this improved capability may remain rather specific to the constraints encountered during sport practice (Ripoll and Latiri, 1997). Although the characteristics of experts’ sensory system remain to be explored, it is widely accepted that these characteristics relatively match the requirements of their sport. Here, we show how the characteristics of the sensory system of expert gymnasts differ from those of other sportsmen and women and match the constraints encountered in gymnastics.

When gymnasts perform a series of acrobatic vaults, they have to cope with unusual and complex perceptual conditions. During somersaults, acrobatic movements produce large head angular velocities over and above those that the visual system can handle in terms of perceptual input. Indeed, for a simple backward somersault, the head rotates at around 17.5 rad·s⁻¹, well out of the usual range for visual perception (e.g. Bardy and Laurent, 1998). In such circumstances, we can assume that the visual system is unable to pick up any relevant information in the environment (see the theoretical work of Pozzo and Studeny, 1987). In line with this observation, Graydon and Townsend (1984) claim that vision is not a major source of information for gymnasts. Interestingly, they showed that trampolinists performed a forward somersault better when they were blindfolded, suggesting that visual information may actually disrupt execution of the movement. In contrast, others have shown that vision is important for performing acrobatic movements. For instance, Bardy and Laurent (1998) showed that gymnasts used vision to control a backward somersault. Robertson et al. (1994), comparing the ability of expert and novice gymnasts to cross a balance beam, found that vision is required for novices and experts alike (see Robertson and Elliott, 1996a,b). The issue of whether gymnasts can control the execution of complex moves in the absence of or with reduced visual cues is still unclear.

Most studies of the properties of the perceptual system of expert athletes have been based on one specific athletic task. As a result, it is unclear whether such findings can be generalized to more natural and simple tasks. The main aim of this study was to determine whether gymnasts are affected by the absence of vision in a more neutral task – displacing as straight as possible. A secondary aim was to establish the potential contribution of proprioceptive and vestibular cues in such circumstances. To address these issues, we used the common ‘suppression sensorial paradigm’ (Benson et al., 1989; Nemire and Cohen, 1993; Fitzpatrick and McCloskey, 1994; Bringoux et al., in press); that is, we observed how the absence or reduction of a particular type of sensory cue altered individuals’ performances. Although simple linear additive models of sensory integration have been shown to be incorrect (Gibson, 1966; Oman, 1982; Stoffregen and Riccio, 1988), when performance is diminished, researchers agree that remaining cues are insufficient for adequate movement control (i.e. the cue that was removed was crucial for performance of the task). In contrast, when performance is maintained, it does not necessarily indicate that the removed cue is not useful. The same information can be provided by several sensory systems (Cutting and Vishton, 1995), allowing individuals to switch between modalities depending on the context (Warren and Schmitt, 1978).

The ability to achieve displacement during blindfolded locomotion has been widely studied. Although several studies have shown that it is possible to maintain a sense of the location of nearby objects after closing one’s eyes (Loomis et al., 1992), humans are unable to maintain a displacement in a straight line for long (for an historical review, see Cicinelli, 1989). Most people deviate quickly from the initial trajectory after several metres of displacement (Boyadjian et al., 1999). This tendency to depart from linearity during locomotion is called ‘veering’ (Golledge et al., 1996). Because gymnasts are accustomed to dealing with circumstances in which poor visual information is available for the control of movement, they might be less affected by the removal of vision than sedentary individuals or experts in ‘open-skill’ sports. Therefore, we investigated two other sensory modalities potentially useful to the performance of the task: the proprioceptive modality in relation to the multiple receptors located in the limbs (muscle, joint and cutaneous receptors) and the vestibular modality in relation to the labyrinthine system. In an attempt to discriminate between these modalities, an additional task was included in the protocol. We selected a task in which blindfolded individuals displaced passively, so that the flow of proprioceptive cues would be greatly reduced, without much change to the flow of vestibular cues. If veering worsens in such a condition, it would indicate that proprioceptive cues are helpful during blindfolded locomotion and that vestibular cues alone cannot compensate for the lack of proprioceptive and visual cues. Because our findings may originate simply from the practise of sports in general, the gymnasts’ performance was compared with that of a control group of non-gymnasts who were experts in other sports.

Methods

Participants

Two groups of athletes from the Faculty of Sports Sciences at the University of Grenoble volunteered to participate in the experiment. The group of eight expert gymnasts (5 females, 3 males) were aged 18–25 years
and were 155±177 cm tall. All of the expert gymnasts had more than 10 years experience in gymnastic competition at regional standard or higher. The eight members of the control group (4 females, 4 males) were aged 19–24 years and were 159–180 cm tall. All controls had more than 10 years experience of sporting competition other than gymnastics (soccer, handball, basketball, climbing or tennis) at regional standard or higher, so that they were also experts in their own sports.

**Task and procedure**

Our protocol was similar to that used by Boyadjian et al. (1999) when evaluating the role of the limb effectors responsible for veering. At the beginning of each trial, the participant was placed in the centre (point O) of a 30-m diameter circle (see Fig. 1). The experimental area was a flat gymnasium without any obstacles. The participant was instructed to move 15 m in a straight line, without specifying the initial direction of motion. After verifying that all participants walked straight with full vision, three conditions of blindfolded locomotion were introduced to each individual. In the ‘LEG’ condition, the participants were instructed to walk in a straight line. In the ‘ARM’ condition, the participants were asked to steer a wheelchair in a straight line. Finally, in the ‘VERB’ condition, the participants also displaced in a wheelchair, but were pushed by a second person instructed to follow the participant’s verbal orders (‘Go left! Go a little to the right’).

At the beginning of each ‘VERB’ trial, the pusher of the wheelchair was instructed to perform a straight displacement for the first 2 m. He was then instructed to initiate a turn either to the right or to the left, with right and left turns being randomized. Before the experiment, the participants were informed of the existence of these turns. Each condition was organized as a block of 15 trials. The order of presentation of these three blocks was pseudo-randomized between participants; that is, we made sure that each of the six possible sequences of blocks was tested in each group. In all experimental conditions, the participants were asked to displace at a pace they felt comfortable with. There was no feedback on performance throughout the experiment: the participants remained blind between the trials of each experimental condition by wearing dark goggles. To prevent fatigue, 10 min of rest was allowed between conditions.

In the LEG and ARM conditions, displacement was active. Therefore, except for the visual organ, the remaining sensory organs (in particular, vestibular and proprioceptive) were not impaired and could, potentially, provide information to update body trajectory. In contrast, when the participants displaced passively in the wheelchair (VERB condition), the flow of proprioceptive signals resulting from the movement of the limbs (arms or legs) was greatly reduced. The active wheelchair (ARM) condition was included in the protocol because the walking (LEG) and passive wheelchair (VERB) conditions represent two very different modes of locomotion; we needed an intermediate condition to assess how specific displacement can be in a wheelchair.

Note that this task (maintaining a straight line) is different from the body of work on spatial orientation during blindfolded locomotion (for a review, see Golledge et al., 1996), in which individuals have to move to a previously seen target (Thomson, 1980; Laurent and Cavallo, 1985) or to complete a path consisting of a few straight segments separated by turns (return-to-origin; Klatzky et al., 1990). Indeed, in these experiments, individuals need to match a certain direction and distance; in the present study, they simply had to maintain a direction that was freely chosen by them.

**Data analysis**

 Veering was measured as follows (see Fig. 1). Two concentric circles of 15 and 2 m radius respectively were drawn on the floor. Although we did not record the actual paths taken by the participants (shown in Fig. 1 by the dotted line), in each trial we marked the locations where they crossed the circles (point A for the larger circle and point B for the smaller one). Then, using a piece of string with one end fixed at O (origin of the circles) and the other at point B, we determined the initial direction of the participant’s trajectory. Veering was measured as the perpendicular distance (V)
between point A and this ‘ideal’ straight-line displacement (line O±B). Multiple measurements were performed by independent observers on a given trial, with an estimated accuracy of ±5 cm. One dependent variable was extracted for each participant in each condition. This variable was the mean absolute veering (i.e. ignoring the direction of deviation on each trial). Two-way analyses of variance (group ´ locomotion) were performed with group (gymnasts vs controls) as a between-individuals variable and type of locomotion (LEG, ARM, VERB) as a within-individual variable. When necessary, post-hoc tests, using the Newman-Keuls procedure, were used to examine significant main effects and interactions. For each significant effect, the percent total variance explained is reported using $F$- and $P$-values.

Results

Mean absolute veering is shown in Fig. 2. All participants veered substantially after 15 m of displacement without vision in all experimental conditions. However, there were large differences between the gymnasts and controls. Gymnasts clearly veered less than non-gymnasts ($1.8 ± 1.9$ vs $3.2 ± 0.9$ m; standard deviations represent the variability of each group across the experimental conditions), as demonstrated by a significant main effect of group ($F_{1,14} = 85.4$, $P < 0.01$; accounting for 26% of the total variance). Large differences were also observed between experimental conditions. There was a significant main effect of locomotion ($F_{2,28} = 366$, $P < 0.001$; accounting for 52% of the total variance). However, as indicated by a significant group ´ locomotion interaction ($F_{2,28} = 89.7$, $P < 0.01$), which accounted for 13% of the total variance, the effect of the experimental condition was different for each group. Newman-Keuls post-hoc analyses showed that gymnasts always veered less than non-gymnasts, except in the passive wheelchair (VERB) condition. Additional post-hoc analyses indicated that the gymnasts performed similarly in the active wheelchair (ARM) and walking (LEG) conditions, but performed worse in the passive wheelchair (VERB) condition. In contrast, the performance of the control group was different for each of the three conditions, with performance worsening from walking to active wheelchair and from active wheelchair to passive wheelchair conditions.

Discussion

The discussion has two main sections. The first addresses the fact that, although all participants were affected by suppression of vision, the gymnasts were affected less than other sports experts during active (LEG and ARM conditions) displacement. Based on the results of the passive (VERB) condition, we then examine why the use of proprioception is thought to be the source of the differences between gymnasts and non-gymnasts.

All participants veered in all conditions. This is in line with the results of previous studies, which showed how visual information is fundamental for accurate displacement in the environment (Gibson, 1958; Thomson, 1980, 1983; Burton, 1994). We showed this to be valid even for a simple task such as straight, forward displacement. Therefore, when gymnasts have to rely on other sensory modalities – proprioceptive or vestibular – they are unable to compensate fully for the lack of vision. Thus, gymnasts require visual cues to perform accurate whole-body movements; this is in agreement with the results of Robertson and Elliott (1996a,b) and Bardy and Laurent (1998) for more complex movements.

The comparison between gymnasts and non-gymnasts demonstrated that the gymnasts were affected less by the suppression of vision during active displacement (LEG and ARM conditions). In previous studies, absolute veering measured for sedentary walkers was estimated (because of varying distances and units for the measurement of veering) to range from 1.8 m (Lund, 1930) to 4.9 m (Cratty, 1965) after 15 m of displacement. Although these two studies did not provide information about the sport characteristics of their participants, it is reasonable to consider their pool of participants as a sample of the sedentary population. In contrast, in the present study, absolute veering during walking was only 0.6 m for the group of gymnasts.
This finding indicates that, although gymnasts are dependent on vision, their ability to use the remaining sensory modalities is better than that of experts in other sports and sedentary individuals. Because gymnasts often have to cope with poor visual environments, we suggest that having or developing this ability is a necessary requirement for becoming an expert.

This prompts us to ask the following question: What type of sensory cues do blindfolded gymnasts use to allow them to be more accurate during active displacements? Let us first focus on the findings that are common to both groups. Although we have no direct evidence, it is fair to assume that the proprioceptive cues available to update the body trajectory were greatly reduced in the passive (VERB) compared with the active (LEG and ARM) conditions. We cannot be sure that the vestibular system was stimulated efficiently during veering given the low angular velocities experienced by the participants. However, we do know that more vestibular cues were generated in the passive wheelchair (VERB) condition than in the active wheelchair (ARM) condition, given the initial turn and the larger final deviation in the passive wheelchair condition. Because both groups performed consistently worse during passive displacement, we conclude that, to control blindfolded displacements, gymnasts and expert athletes relied on proprioceptive cues. Note that a similar drop in performance was observed by Sholl (1989) in an experiment in which blindfolded individuals had to return to their initial position after several passive linear displacements in a wheelchair; the accuracy of the participants was poor compared with the condition in which they had to perform the same displacements when walking. The vestibular system does not seem sufficient for the control of linear blindfolded displacements, since deviations of 4 m were observed after 15-m displacements. Consistent with this finding, using the ‘supression sensorial paradigm’, Bringoux et al. (in press) showed that the vestibular system badly updates body orientation during passive tilt. In addition, after being exposed to walking on a rotating disc, Gordon et al. (1995) reported that humans produced curved walking trajectories well above the sensory vestibular threshold, while they actually perceived themselves to be walking in a straight line.

The effects of the experimental conditions were not exactly the same for both groups. In particular, gymnasts always performed better than the controls as long as the proprioceptive system was clearly stimulated (LEG and ARM conditions); as soon as the stimulation was reduced (VERB condition), however, the two groups performed similarly. In addition, although not measured, it is realistic to expect a similar performance by both groups in the presence of vision. Therefore, a characteristic of gymnasts is their use of proprioception in the absence of vision. But why are gymnasts able to rely more on proprioception than experts in other sports? Gymnasts either have a more sensitive proprioceptive system or they have a greater ability to ‘pick up’ crucial information via the proprioceptive system. Either way, it is an advantage for gymnasts, who need to perform complex movements when visual perception might be very limited.

In conclusion, we have shown that, while all sports experts cannot compensate fully for a lack of vision in a simple linear task, expert gymnasts are affected less as long as the displacements are active. Although these results show that gymnasts’ proprioceptive system is more efficient than that of non-gymnasts, it remains to be determined whether this characteristic is the result of practising gymnastics or whether it is a natural aptitude required to reach the highest standard in gymnastics.

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