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Influence of Gymnastic Background on Triangle Completion Performance in Single and Dual-Task Conditions

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Abstract: Spatial orientation skills of gymnasts have been investigated in the past, but their navigation skills have not been well described. For instance, little is known on their performance on triangle completion in the absence of vision. The question is whether gymnasts require less attention than non-gymnasts in executing this task. The aims were to study the impact of dual-task on triangle completion performance and reaction time, and to compare this effect in young adults with or without a gymnastic background. Participants were blindfolded and guided along the first two legs of a 5x5 m right angle triangle and then, independently turned and walked towards the origin of this triangle. After they had stopped, their foot position was marked on the floor and angular deviation and linear distance traveled were measured. In the dual-task, reaction time was gathered during the independent walk with participants responding verbally 'top' as fast as possible after a sound signal. Gymnasts were found to have smaller angular deviation and longer linear distance traveled than non-gymnasts. Both groups showed longer reaction time in dual-task compared to baseline in sitting and this increase was similar for both groups. The results suggest that gymnastics training improves the perception and control of direction. However, it does not modify perception of linear displacement, nor the attention required to execute the triangle completion task. In dual-task, other cognitive tasks requiring working memory might have had a larger impact on both navigation errors and cognitive task performance.

Keywords: Dual-task, Gymnastic, Human, Path integration, Reaction time.

INTRODUCTION

When navigating in the absence of vision, path integration is the mechanism by which position and orientation in space can be updated [1]. Vestibular and kinesthetic inputs form the idiothetic information that interacts with cognitive and motor processes to correctly perceive self-motion and build up a cognitive map of the environment [2-4]. In humans, the most common methodology to investigate path integration is the triangle completion task [e.g. 5-7]. Blindfolded participants are led along two legs of a triangle and then must return unassisted to the origin by completing its final leg. This task requires accurate integration of linear and rotational displacements and accelerations that occur while translating along the legs and rotating at the triangle apexes [8]. In young adults, correlations between the correct and actually performed navigation outcomes (distance and deviation angle) in triangles with two equal legs of 2, 4, or 6 m and turn angles of 60º, 90º, or 120º were as high as $r^2 = 0.92$ [6]. Performance seems related to triangle dimension, as subjects overshot the distance on small 2 x 2 m triangles, but undershot the distance on 3 x 3 and 4 x 4 m triangles [9]. Over-rotation of the second turn angle was obtained when the first angle was of small magnitude (30-60°), but under-rotation was found when the first angle was larger (120-150°) [9].

The first question of this study is whether expertise in the control of body orientation, such as in gymnasts, leads to improved performance in triangle completion. Gymnasts have some of the highest scores among athletes for spatial orientation, likely because they regularly perform series of complex body maneuvers, such as successive tumbling and somersaults [10]. They are able to execute these maneuvers without the direct use of vision during the aerial phase while landing precisely in a pre-designated area [11]. In addition, spatial navigation without vision is well performed in individuals with gymnastic training. For example, when instructed to walk blindfolded in a straight line for 15 m, gymnasts deviated significantly less than soccer, handball, basketball and tennis players [12]. However, this navigation task was simple and we raise the question as to whether gymnasts perform better than non gymnasts in more difficult navigation tasks such as triangle completion.

In addition, this research investigates the attentional demand of triangle completion, on which very little is known. The ability to walk blindfolded towards a target and to concurrently count backward in steps of three showed that the rate of counting was significantly decreased during navigation relative to sitting baseline, and walking speed was significantly slower in dual-task than in navigation alone

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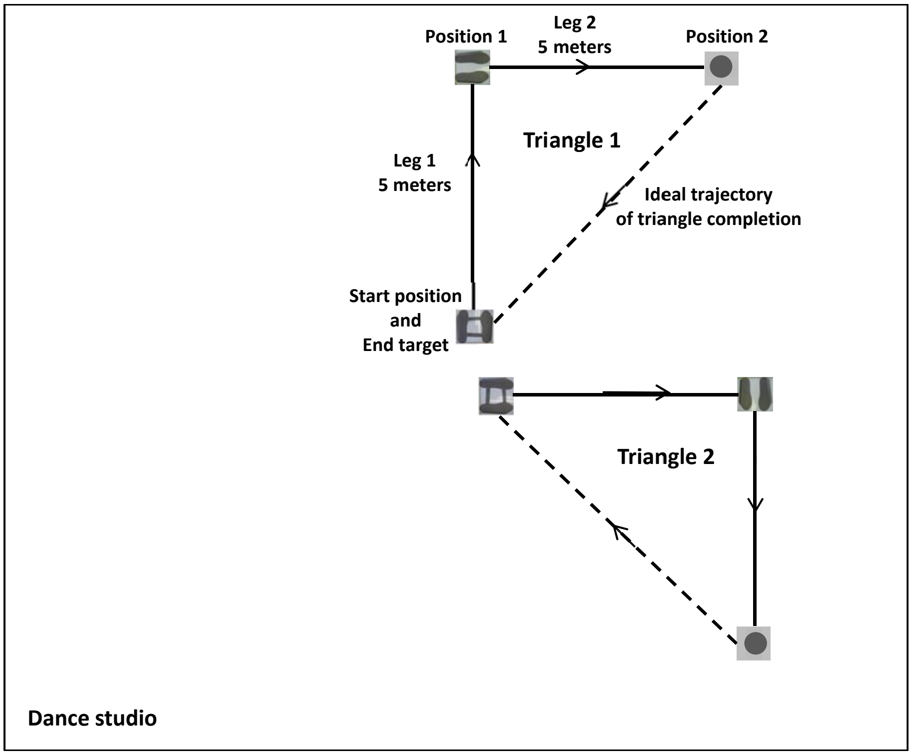

Fig. (1). Experimental set-up. Two 5-m x 5-m triangles were outlined in the dance studio.

[13]. Dual-task was also found to impact on navigation errors when participants were counting backwards in steps of seven while walking blindfolded towards previously seen targets or reproducing a previously walked distance [14]. In both cases, walked distances were significantly longer (overshot) in dual-task than in navigation alone. Thus, performance on either the navigation task or the mental task was impaired in these dual-tasks, which suggests that participants' capacity to simultaneously execute the two tasks was exceeded, as proposed by the hypothesis that the attention capacity of individuals is limited [15].

The second question of this study is whether performance in triangle completion deteriorates when it is concurrently done with a secondary cognitive task. Is such possible deterioration less in individuals with a gymnastic background than in non-gymnasts? In a previous study, reaction times were found to vary along the blind navigation path, and that they were longest at target approach [16]. To obtain the highest possible dual-task impact, reaction time cues were delivered near target approach in the present study. The first aim of the current study was to determine whether performance on triangle completion is different between individuals with a gymnastic background and non-gymnasts. The second aim was to investigate the effect of dual-task at the moment of target approach on triangle completion and reaction time performances and to explore whether a gymnastic background affects this dual-task.

It was hypothesized that the gymnast group would have significantly better angular deviation and linear distance traveled outcomes than the non-gymnast group on triangle completion, and that in dual-task these outcomes as well as reaction times would significantly deteriorate in both groups, with smaller changes in the gymnast group than in the non-gymnast group.

METHODS

Participants

Two groups of 16 young adults participated in this study. They all signed an informed consent form approved by the Ethics Committee of the University of Ottawa. Participants in the first group were required to practice a sport involving spatial orientation and fine movement control. The group was composed of 7 men and 9 women gymnasts between 18 and 26 years of age (mean 21.1 ± SD 2.1) who had trained on average for 11.8 ± 4.1 years. After they had reached their highest level of competition, they maintained this level during 3.6 ± 2.0 years on average. The majority was not competing anymore, but was still practicing on average 9.3 hours per week. They all performed vault and floor gymnastics and women practiced additional beam and bars exercises. A few men practiced additional bars, rings and pommel exercises. The non-gymnast group was composed of 8 men and 8 women between 19 and 30 years of age (23.1 ± 3.5 years). They exercised for 4.0 ± 1.9 hours per week, all performed resistance and cardio exercises, and a few were either running, walking or swimming.

Experimental Set-Up and Procedures

Fig. (**1**) illustrates the experimental set-up in a dance studio in wheretwo 5 x 5 m right triangles were drawn on the floor. Trials were alternated on the two triangles to prevent possible knowledge of position in space over time and repetitive trials. Participants were not shown these triangles and remained blindfolded throughout the duration of the

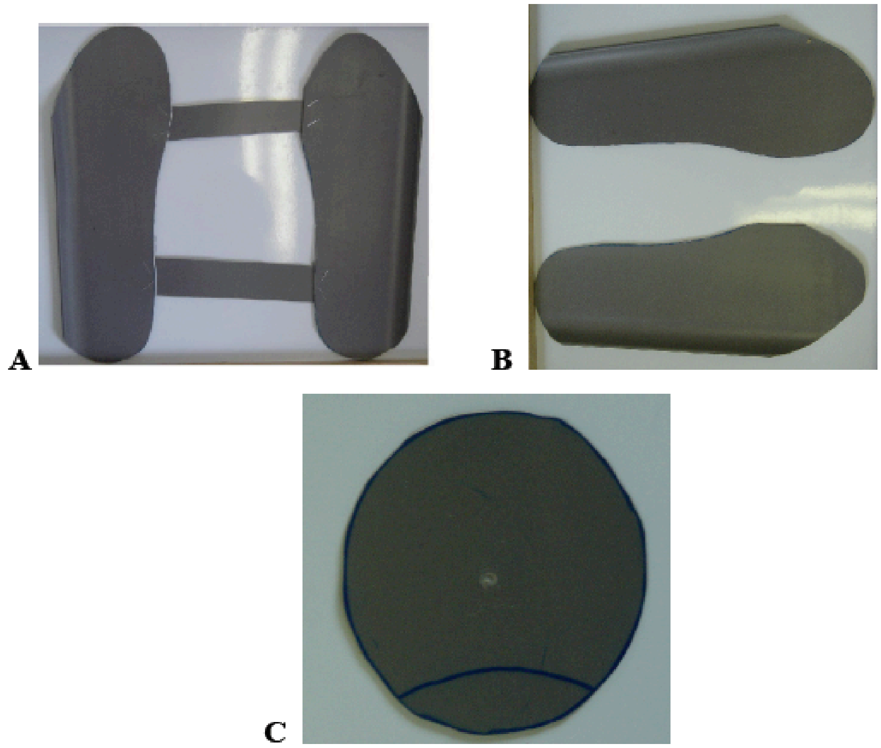

Fig. (2). Shape of feet (**A** and **B**) and circle (**C**) cut from smooth vinyl siding were used to outline the triangle.

testing session. To optimize precision of navigation over the first two legs, 'tactile cues' were used in the form of two pairs of footmarks (Figs. **2A** and **2B**) and a circle, 9-cm in diameter (Fig. **2C**). These were cut out from vinyl siding and placed at the corners of the triangle, as illustrated in (Fig. **1**). One pair of vinyl feet was attached to each other, while the other pair and the circle were taped to the ground.

Participants were led to the starting position while wearing opaque goggles that completely blocked all vision. To ensure that participants felt the vinyl footmarks, they only wore sox (no shoes). They stood at the starting position facing position 1 with their feet well positioned on the vinyl footmarks andthe sighted guide standing behind them. They walked forward and stopped when they contacted the vinyl footmarks in position 1 with their feet. The sighted guide followed and ensured that a straight path was being taken by delicately pulling on a gait belt worn by the participant. This was done only when necessary and involved minimal intervention. The vinyl footmark was removed as soon as participants began their walk. When at position 1, participants rotated 90° clockwise independently, until they felt that their feet were properly aligned with the vinyl footmarks. They were then steered again by the guide along the second leg of the triangle and stopped when they reached the vinyl circle at position 2. At this point, their task was to turn clockwise and walk on their own at a comfortable pace to the end target i.e. the origin of the triangle. After they had stopped, their foot position was marked on the floor with masking tape that was previously labeled with the trial number. Participants were guided back to the starting position through a confusing path to avoid knowledge of results andopaque goggles were worn at all times. They were given two practice trials and then performed ten trials of the triangle completion task.

Baseline reaction times were gathered before participants began the triangle completion trials. Participants were seated and blindfolded, and instructed to verbally respond "top" to a sound signal as quickly as possible. The sound signal was presented 15 times with unequal intervals to prevent anticipation [17]. The signal was a brief sound at a frequency of 1000 Hz for 50 ms that was produced by a speaker triggered by a remote control. The speaker was placed in a pouch attached at participant's waist, to prevent that subjects localize their position in the room from sound signals. A portable sound recorder (Sony ICD-UX70, Sony Corp, China) was used to record the sound signal from the speaker as well as participants' voice.

In the dual-task condition, participants performed the same triangle completion task, but during their independent walk to the end target, they had to verbally respond "top" to the sound signal as fast as possible. One sound signal was given during their approach of the target, i.e. in the last half of their walk. Participants were instructed that the primary task was to accurately complete the triangle, while the secondary task was to respond to the sound signal, completing a series of 34 trials. The sequence was five triangle completion trials, 12 dual-task trials, five triangle completion trials, and then 12 dual-task trials. Four trials without sound signal, i.e. catch trials, were randomly included in the 24 dual-task trials.

Data Collection and Analyses

Two measures were taken from each of the foot marks: angular deviation and linear distance traveled. Fig. (**3**) shows that angular deviation was determined as the angle between the ideal trajectory and the straight line to the final foot position beingmeasured with a laser level (Einhell, BLL400). Deviation to the left of the ideal trajectory was negative and

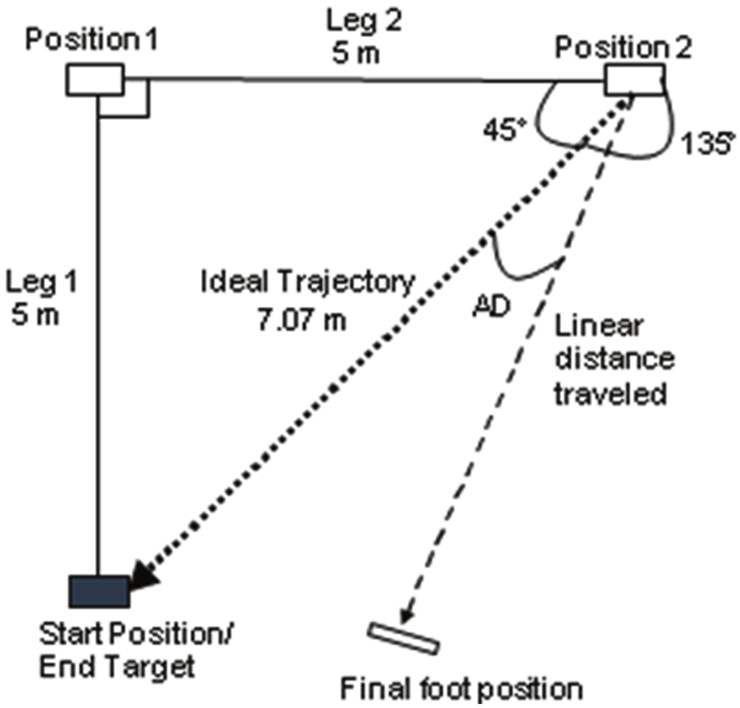

Fig. (3). Example of a triangle completion trial showing the final foot position. Measures of linear distance traveled and angular deviation (AD) are illustrated.

deviation to the right was positive. The linear distance walked between position 2 and the foot mark was measured with a measuring tape. The recorded voice data was transferred to an audio editing program (Audacity 1.2.6) andreaction time was determined by measuring the time in ms between the first deflection of the trace at the moment of the sound signal, and the first deflection of the trace at the moment of the verbal response.

Two-way ANOVAs on group (gymnast vs. non-gymnast) x condition (triangle completion vs. dual-task) was performed on deviation and linear distance traveled. For reaction times, a two-way ANOVA on group (gymnast vs. non-gymnast) x condition (sitting vs. dual-task) was done. Statistics were performed with IBM SPSS Statistics 20 and eta square defined effect size. Significant main effects and interactions were reported at $\alpha = 0.05$.

RESULTS

Fig. (**4A**) illustrates that there was a significant main effect of group, $F(1, 1084) = 75.148$,eta^2 = .052,$p < 0.001$ on linear distance traveled. Gymnasts overshot the ideal distance, while non-gymnasts did not. There was no effect of condition, $F(1, 1084) = 3.48$,eta^2 = .000,$p = 0.062$ and no significant interaction between group and condition, $F(1, 1084) = 0.033$,eta^2 = .000,$p = 0.856$.

On average, both groups deviated slightly to the left of the desired target as shown by negative angular deviation values in Fig. (**4B**). A significant main effect of group was found, $F(1, 1084) = 24.79$,eta^2 = .022,$p < 0.001$, with gymnasts deviating less than non-gymnasts. There was no significant main effect of condition, $F(1, 1084) = 0.191$,eta^2 = .001,$p = 0.662$ and no significant interaction between group and condition, $F(1, 1084) = .000$,eta^2 = .000,$p = 0.984$.

Fig. (**4C**) shows reaction times obtained in both groups during sitting (single task) and dual-task. There was a significant main effect of condition, $F(1, 1069) = 239.1$,eta^2 = .168,$p < 0.001$, with mean reaction time in dual-task significantly longer than in the baseline sitting condition. There was no significant main effect of group, $F(1, 1069) = 0.893$,eta^2 = .001,$p = 0.345$ and no significant interaction between group and condition, $F(1, 1069) = 0.024$,eta^2 = .000,$p = 0.876$.

DISCUSSION

This study's aims were to compare performance on triangle completion between gymnasts and non-gymnasts and to determine the effect of dual-task on triangle completion performance and reaction times in both gymnasts and non-gymnasts. It was expected that triangle completion outcomes would be better in gymnasts than in non-gymnasts, and that possible deterioration of these outcomes in dual-task condition, as well as changes in reaction time, would be smaller in gymnasts than in non-gymnasts.

The present experiment revealed two main findings. First, gymnastic background did influence triangle completion performance. Gymnasts had smaller angular deviation, but longer distance traveled than non-gymnasts. Second, in the dual-task condition only reaction time was affected, not triangle completion accuracy. This effect was the same in both groups of participants.

It was expected that participants with a gymnastic background would perform better than non-gymnasts on the triangle completion task, once gymnasts likely develop spatial orientation skills through practice of vault and floor gymnastic, as well as beam, bars, rings and pommel. Results of this study only partly support this hypothesis, as gymnasts

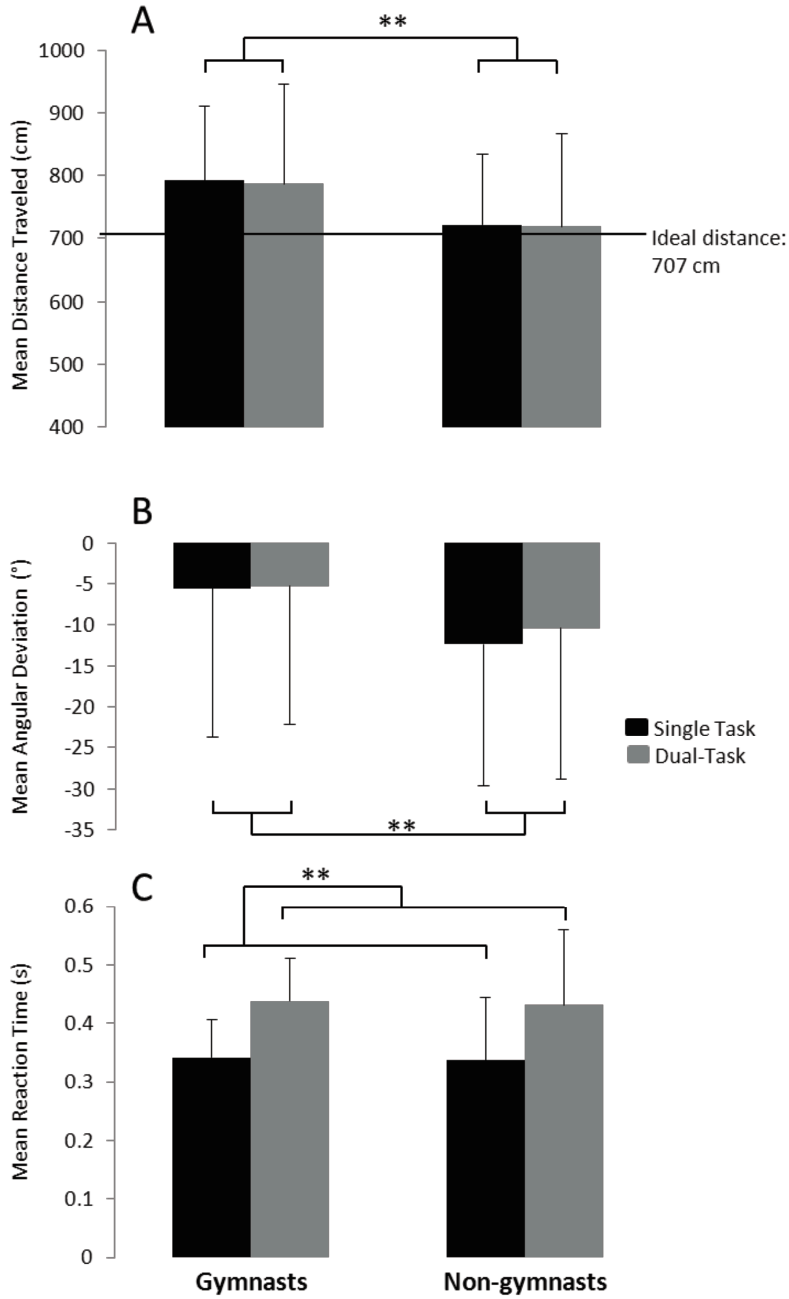

Fig. (4). (**A**) Mean (+1 SD) Linear distance traveled, (**B**) Angular deviation and (**C**) Reaction time by gymnasts and non-gymnasts across conditions. ** $p<0.001$.

performed better than non-gymnasts in terms of direction (angular deviation) but not for linear distance traveled. Gymnasts are known to have an improved sense of orientation [18-20] that may be due to their experience in situations where sensory information was lacking from either vision, somatosensation, or both senses [18]. During the performance of somersaults, head velocities could reach up to 1000 °/s, which is far beyond the 350 °/s maximal head velocity for the vestibulo-ocular reflex to stabilize the image on the retina [21]. Thus, gymnasts may develop alternative strategies to efficiently pick up remaining perceptual cues from other available sensory inputs [11]. In blind navigation studies, gymnasts were found to deviate significantly less than non-gymnasts when walking a straight 15 m path without vision [12]. Altogether, available results suggest that gymnasts better perceive angular deviation from vestibular and kinesthetic inputs, and better control direction than non-gymnasts during navigation in the absence of vision.

However, gymnasts were not better than non-gymnasts in walking the correct distance to complete the triangle. Even though this result was unexpected, it further supports the proposition that control of distance and direction in path integration are independent [22]. The inability of gymnasts to accurately estimate linear distance in triangle completion suggests that gymnastics training does not improve linear displacement perception. This may be explained by the specificity of training theory [23-25]. For instance, rugby players who are evolving in large environments were found to be more accurate in triangle completion than martial artists because they made smaller direction errors [26]. In blind navigation towards a previously seen target, athletes and non-athletes performed equally at comfortable gait speed, but athletes were more accurate than non-athletes at fast velocity [27]. This is likely because athletes were experienced with moving rapidly and could better process idiothetic information during fast displacements than non-athletes. Then, different forms of training may differently modulate the ability to perceive distance and direction in path integration. Participants of this study who were practicing general physical activities were accurate in walking the correct distance, while gymnasts were accurate in heading towards the triangle origin.

To examine the amount of attentional demand at target approach during triangle completion, a dual-task experimental protocol that is hinged on the capacity model of attention was used [28]. The amount of mental work that can be performed by an individual at a specific instant is assumed to be limited, andeach task requires an amount of attention [28]. If two tasks performed concurrently surpass the available capacity to process information, they interfere with each other and cause the performance on one or both tasks to deteriorate [15,29]. Mean reaction time in dual-task was about 100 ms longer than in sitting, which indicates that when triangle completion and reaction time tasks were concurrently performed, they exceeded participants' information processing capacity. However, reaction time was impaired in dual-task, but triangle completion accuracy was not. This may be due to a task prioritization effect [30] sinceparticipants were instructed to give priority to triangle completion over the reaction time task. This result is in contrast with significantly higher homing gains found in dual-task condition when the mental task was performed when homing, but it is not clear which task was the primary one in this study [14]. Thus, the influence of instructions given to participants regarding task priorization remains to be determined in dual-tasks involving spatial navigation.

Another possibility to explain that no significant main effect of condition on triangle completion performance was found is the large inter-subject variability in distance traveled and deviation angle, with 13.8% and 21.9% coefficients of variation, respectively. Thus, the ability to perform triangle completion varied from good to poor among participants. This is why the present triangulation protocol has been developed in which path acquisition was carefully standardized with the use of vinyl footmarks. It was expected that those modifications would improve performance consistency, but clearly it did not. This is probably because triangle completion involves the processing of several sensorimotor and cognitive information [3], and that there are possibilities of error at multiple levels. Therefore, integrating linear and rotational accelerations [6,9], building a mental representation of the previously covered path [2], and estimating the route's direction and distance from these elements [31] are easy to do for some participants and more difficult for others. So far, this between-subject discrepancy has not been correlated with any specific individual factor.

Reaction time was significantly longer in dual-task than in sitting, but this effect was the same in both groups, suggestingthat triangle completion was not less demanding on attention for gymnasts than non-gymnasts. This may be because all participants were inexperienced with both triangle completion and reaction time tasks. Performing new tasks may involve high attention loads that are not influenced by specific sport background. Another possibility is that all participants were actively involved in at least one sport. Perhaps the difference in physical activity level and sport background between the two groups was insufficient to confirm possible differences in the attentional demand of triangle completion. Impaired navigation outcomes obtained in older compared to young adults on passive triangle completion were found to be correlated with cognitive test outcomes, especially speed of processing and working memory capability [31]. This further indicates that execution of triangle completion requires cognitive resources.

The different type of cognitive resources involved in reaction time and triangle completion may explain why no effect of group and no effect of dual-task on triangle completion outcomes were found. In fact, it is possible that competition between the two tasks in this study was only partial. Studies on route guidance in the absence of vision shed light on this hypothesis [32,33]. When guidance was provided by verbal instructions that are known to require working memory, the addition of a secondary vibrotactile N-back task was more detrimental than when guidance was given by spatialized audio cues that are less demanding on working memory. Since N-back tasks generate a cognitive load, it likely competed more with the higher cognitive processing of verbal instructions than with simpler audio cues. In this study, it is possible that reaction times did not compete with triangle completion for working memory, explaining why triangle completion performance was not affected by reaction times. In contrast, triangle completion did perturb reaction times, likely because it consists of a much larger mental effort than just sitting.

This study provides novel information on the ability of young adults, gymnasts or not, to perform blind navigation in single and dual-task condition. Training involving control of body orientation such as in gymnastic does not seem to translate into improved performance on blind triangle completion under divided attention conditions. This new knowledge, although preliminary, provides a better understanding of how spatial orientation competencies can be related or not to specific sport training.

CONCLUSION

Gymnastic background influenced triangle completion performance in the single task, but not in dual-task. In this study, the occurrence of reaction times was limited to the moment of target approach. In future research, the duration of the secondary mental task, thus the period of task concurrence, could be expanded and cover the whole requirement of turning independently and walk towards target. It will be important to explore whether other mental tasks better compete with the cognitive processes involved in triangle completion, especially for attention.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflicts of interest.

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