SPATIAL PERCEPTION OF WHOLE-BODY ORIENTATION DEPENDS ON GYMNASTS' EXPERTISE

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Abstract

The perception of spatial orientation of the body is a fundamental process in the precise performance of complex motor tasks, such as those found in acrobatic sports. While visual information is thought to be an important informational source when performing gymnastics skills, it is still questionable, which role visual information plays in the perception of spatial orientation in matters of gymnastics expertise and task specificity. Thus, this study targets the question, which role visual information plays in the perception of spatial orientation as a function of specific task demands and gymnastics expertise. High-skilled and low-skilled gymnasts were compared in their estimation of body tilt while being rotated about the transverse axis and the anterior-posterior axis in a human gyroscope with either full visual information available or occluded visual information. Results revealed that high-skilled gymnasts exhibited a better estimation of body tilt as compared to low-skilled gymnasts. Estimated tilt angles varied as a function of rotation axis and expertise, but not as a function of visual information. It was concluded that an increased spatial orientation ability may result from an increased sensitivity in individual sensory systems, and/or from an optimized processing of interacting sensory information that is specific to gymnasts' experience with particular motor tasks and the corresponding task demands.

Keywords: *human gyroscope, artistic gymnastics, task demands, task specificity.*

INTRODUCTION

The perception of spatial orientation of the body is a fundamental process in the precise performance of complex motor tasks, such as those found in acrobatic sports (Bringoux, Marin, Nougier, Barraud, & Raphel, 2000; von Laßberg, Beykirch, & Campos, 2015). Information on spatial orientation is derived and integrated from multiple sensory cues, such as tactile cues, proprioceptive cues, visual cues, and vestibular cues (Magill, 2011; Sato, Velentzas, & Heinen, 2016), but also cues from other sources are discussed (von Gierke, & Parker, 1994). Perception of spatial orientation is an important prerequisite for precise and rule-consistent task performance in sports such as artistic gymnastics, where task execution is an important judging criterion (Bučar, Čuk, Pajek, Karacsony, & Leskošek, 2011). While visual information is identified as an important informational source when performing gymnastics skills, it is still questionable, which role visual information plays in the perception of spatial orientation as a function of gymnastics expertise and specific task demands (Gautier, Thouvarecq, & Chollet, 2007; Raab, de Oliveria, & Heinen, 2009).

Theoretical approaches argue that sports performers develop contingencies between sensory information and their corresponding motor actions during motor skill acquisition processes, and during motor training (Hodges & Williams, 2012; O'Regan & Noë, 2001). Thus, gymnasts' exposure to particular motor tasks (with their specific sensory input) shapes the aforementioned contingencies in a task-specific manner, so that skill performance is thought to be specific to the task demands, as well as to the sources of information available during skill acquisition (see also Heinen, Mandry, Vinken, & Nicolaus, 2013; Keetch, Schmidt, Lee, & Young, 2005; Moradi, Movahedi, & Salehi, 2014; Proteau, 1992). On a perception side, the aforementioned contingencies contain information about the input from the different sensory systems, as well as about the interaction of this input (Davids, Button, & Bennett, 2008). Thus, spatial orientation is a multisensory percept (Naylor & McBeath, 2008).

The visual system is, for example, able to provide information on athletes' spatial orientation when fixating gaze on distal environmental cues, or when picking up optical flow information (Latash, 2008; Sato et al., 2016; Wade & Jones, 1997). Visual information, however, is the most trusted information for the human brain, and there is usually an immediate decrease in spatial orientation when people perform with eyes closed (Magill, 2011). Davlin, Sands, & Shultz (2001) analyzed for instance gymnasts' performance in back somersaults under different vision condition such as vision available during the entire somersault, vision available either during the first or the second half of the somersault, and no vision available during the somersault. Results revealed that gymnasts landing performance was significantly constrained when no vision was available or when vision was available during the first half of the somersault, indicating that visual information might be important during the last half of the flight phase in order to contact the landing mat with an adequate body orientation and to perform a precise landing (see also Luis & Tremblay, 2008).

Danion, Boyadjian, and Marin (2000) investigated expert and novice gymnasts' locomotion behavior in the absence of visual information input. Participants were asked to perform three tasks of blindfolded locomotion (walking, steering a wheelchair, and verbally instructing a second person pushing their wheelchair). Results revealed that expert gymnasts exhibited fewer veers during blindfolded walking or blindfolded wheelchair steering as compared to novices. The authors concluded that expert gymnasts are more sensitive to input from other sensory systems in case visual information is not available during spatial orientation tasks.

Naylor and McBeath (2008) examined the perception of spatial orientation as a function of gender, and as a function of different sensory cues. The authors asked students to estimate body tilt about the transverse axis under different sensory cue conditions (i.e., presence or absence of visual and/or auditory cues) while being rotated in a whole-body rotation device (Aerotrim© gyroscope). Results revealed a strong bias when no visual information was available, and participants tended to overestimate body tilt. However, estimating body tilt was, in general, most precise in the presence of visual cues, and there was a slight gender difference in estimating spatial orientation. The authors concluded that perception of body tilt is a multisensory, and gender-dependent process, while visual information plays a stronger role in spatial orientation as compared to auditory information.

Bringoux et al. (2000) investigated the role of somatosensory and vestibular cues in the perception of body orientation about the transverse axis. Expert gymnasts and non-gymnasts were slowly rotated about the transverse axis in a whole-body rotation device. Participant's task was to detect changes in body orientation with closed eyes. Results revealed that expert gymnasts were more sensitive to changes in body orientation than novices. Furthermore, experts were more precise in the perception of body orientation when compared to novices. The authors concluded that experts' exposure to training may drive their superior ability for spatial orientation, leading to a more precise perception of body orientation about the transverse axis.

To sum up, it is stated that experts or high-skilled gymnasts exhibit an improved ability for spatial orientation as compared to novices or low-skilled gymnasts (Heinen, Jeraj, Vinken, & Velentzas, 2012; von Laßberg et al., 2015). This ability is thought to stem from adaptations in the sensory motor system due to gymnasts' exposure to skill acquisition processes, and these adaptations are thought to manifest in an increased sensitivity to sensory cues (Hodges & Williams, 2012; von Lassberg, Beykirch, Campos, & Krug, 2012; Williams & Ericsson, 2005). Nevertheless, gymnastics skill performance is thought to be specific to the task demands, as well as to the sources of information available during skill acquisition. Thus, this study targets the question, which role visual information plays in the perception of spatial orientation as a function of specific task demands, and gymnastics expertise. The aim of this study was twofold: First, it should be confirmed that high-skilled gymnasts exhibit a better perception of body orientation than low-skilled gymnasts under changing task demands. Second, it should be determined if high-skilled gymnasts exhibit a better perception of body orientation than low-skilled gymnasts as a function of the availability of visual information.

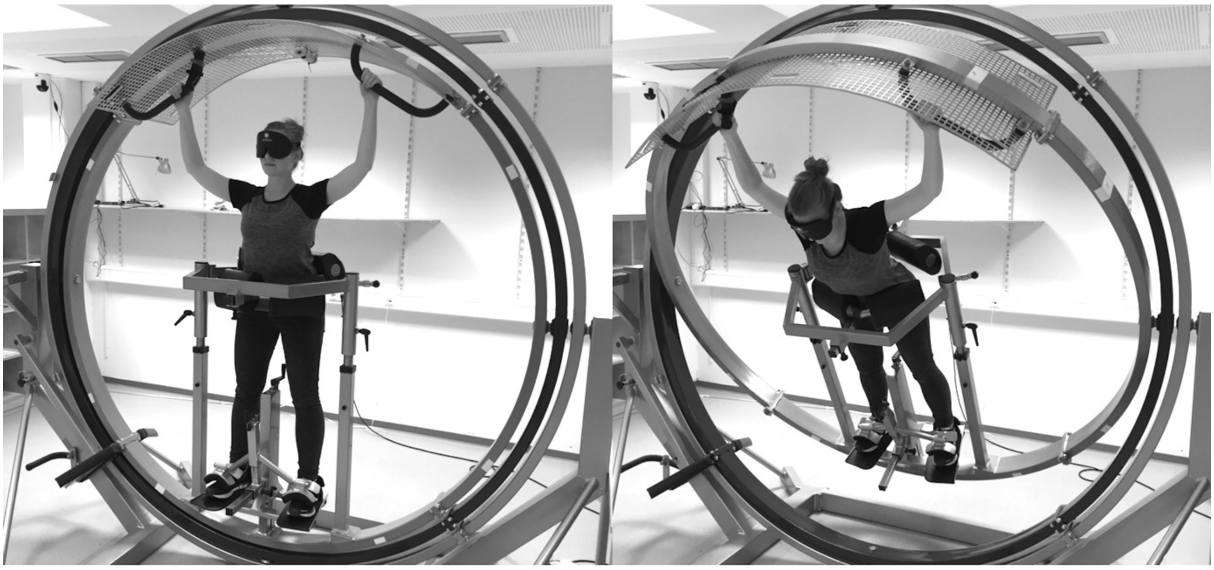
The methodological approach of this study was an extension of the approach utilized in the study by Naylor and McBeath (2008). Additionally, an expert-novice approach was used, and visual information was manipulated while participants were rotated about two different body axes (Bringoux et al., 2000; Williams & Ericsson, 2005). It was expected that perception of spatial orientation is most precise when visual information is available (Naylor & McBeath, 2008). It was furthermore expected that high-skilled gymnasts, in general, outperform low-skilled gymnasts in the spatial orientation task, independent of the availability of visual information (Bringoux et al., 2000). There was no specific prediction of whether perception of spatial orientation differs as a function of the rotation axis, but we sought to explore this effect.

METHODS

The study sample consisted of a total of N = 20 gymnasts. The number of participants was derived from a power analysis when expecting a medium effect (Cohen's f = 0.25) with type I error probability of 5%, and type II error probability of 20%, given the results of the aforementioned studies. A subgroup of n_1 = 10 participants (university students; age: M = 23.2 years, SD = 2.1 years) had basic gymnastics experience due to their successful participation in a level 1 gymnastics course at the local university, in which self-realizing methodical progression of basic gymnastics elements such as rolls and cartwheels was the main content. They were labeled as 'low-skilled' gymnasts. Another subgroup of n_2 = 10 participants (former and current artistic gymnasts; age: M = 23.3 years, SD = 2.2 years) in this study had more comprehensive experience in gymnastics with a minimum training amount of four hours per week and at least six years of participation in competitive gymnastics. They were labeled as 'high-skilled' gymnasts in this study (Heinen et al., 2012). In order to prohibit potential gender effects, only female gymnasts were recruited (Naylor & McBeath, 2008).

The high-skilled and low-skilled gymnasts were asked to participate in an experiment on spatial perception. They were informed about the procedure of the study, and they were asked to give their written consent prior to the study. The study was carried out in accordance with the local universities' ethical guidelines.

Human gyroscope. This study utilized a 3D-SpaceCurl human gyroscope (approximate weight: 300 kilograms; see Figure 1 and www.spacecurl.de). The SpaceCurl allows for a controlled rotation of the body about any rotation axis (Bersiner & Heinen, 2016). The outer ring of the used gyroscope had a diameter of approximately 2.40 meters. The SpaceCurl gyroscope was located in a laboratory room of the Institute of Sport Science of the local university. Participants were placed in the gyroscope in an upright standing posture. Their standing height in the gyroscope was set by a vertically adjustable platform so that their center of mass position aligned with the rotation axis of the gyroscope. Current tilt angle of the gyroscope was measured by a gyro sensor attached to the outer ring of the gyroscope. The sensor measured at a frequency of 100 Hz and was connected via Bluetooth to a desktop computer.



a) b)

Figure 1. SpaceCurl human gyroscope with a participant in vertical position (a), and in forward rotated orientation (b). The gymnast is wearing the Mindfold® mask. The gyroscope sensor is attached to the top of the inner ring of the gyroscope.

Manipulation of visual information. Visual information was manipulated by either allowing participants to use full visual information, or by blindfolding them (full vision vs. occluded vision; Davlin, Sands, & Shultz, 2002). In order to blindfold participants, a so-called Mindfold® mask was used (see www.mindfold.com). The Mindfold® mask is a flexible black plastic plate backed with a soft foam padding with cut-outs for both eyes. When wearing the Mindfold® mask, the participant experiences total darkness. The mask was held in place with a soft head strap (see Figure 1).

Tilt estimation task. The participant was placed in the gyroscope, and the gyroscope was tilted at a constant velocity of six degree per second (Naylor & McBeath, 2008). Participants' task was to indicate when her body was tilted 45 degrees away from the vertical, either about the transverse axis ('somersault axis'), or about the anterior-posterior axis ('cartwheel axis'; see also Naylor & McBeath, 2008). The participant was rotated forward and backward from an initial upright position (absolute vertical: zero degrees) about the transverse axis, and she was rotated clockwise and counterclockwise about the anterior-posterior axis (Ito & Gresty, 1997). Participants responded by pressing a small button that was attached to the handle of the dominant hand. The button was connected via Bluetooth to the desktop computer (see above). When the button was pressed, the current tilt angle about the transverse axis was recorded and the rotation of the gyroscope was stopped. Immediately after the rotation was stopped, the participant was rotated back to the initial position. The participant received no feedback on current tilt angle in any of the trials. Twelve trials were realized in each experimental condition. The difference between each of the twelve values of each participant and the criterion angle of 45 degrees was calculated. The twelve difference values of each participant were averaged for further data analysis.

The study was conducted in three phases. In the first phase, each individually tested participant arrived at the laboratory. She was informed about the procedure of the study, and she was asked to complete the informed consent form along with a short demographic questionnaire. After providing informed consent, the participant was shown a diagram of a 45-degree angle. This was done for calibration purposes (Graziano & Raulin, 2008). In the second phase, the data collection took place. The gymnast was placed in an upright standing posture in the gyroscope. She was rotated at a constant velocity either about the transverse axis, or about the anterior-posterior axis, with full vision available or with no vision available. The participant wore earplugs in order to block auditory information. She was asked to indicate when her body was tilted 45 degrees, and she responded by pressing a small button attached to the handle of her dominant hand. This procedure resulted in four conditions that were presented to the participant: (1) rotation about the transverse axis with full vision, (2) rotation about the transverse axis with occluded vision, (3) rotation about the anterior-posterior axis with full vision, and (4) rotation about the anterior-posterior axis with occluded vision. In each condition, twelve trials were realized, leading to a total of 48 trials for each participant. Conditions were presented in a randomized order and the participant was allowed to rest as needed. In the third phase of the study the participant was debriefed, and she received a small token of appreciation for her participation.

A significance level of $\alpha = 5\%$ was established for all results. In order to test the main hypotheses, a 2 (*Group:* high-skilled vs. low-skilled) × 2 (*Rotation Axis:* transverse axis vs. anterior-posterior axis) 2 (*Visual Information:* full vision vs. occluded vision) analysis of variance (ANOVA) with repeated measures was conducted, taking the differences between estimated tilt angles and the criterion angle of 45 degrees as dependent variable. *Group* was treated as a between-subject factor. *Rotation Axis* and *Visual Information* were treated as within-subject factors. Concerning the assumptions of the ANOVA, a Shapiro-Wilk test indicated that the sample data could be assumed to come from a normally distributed population (Atkinson & Nevill, 1998). Furthermore, Mauchly's sphericity test indicated that the sphericity assumption was not violated for the repeated measures factors. Therefore, no correction of the degrees of freedom was necessary (Atkinson & Nevill, 2001). Post-hoc analyses were carried out using Fisher's least significance difference test in order to explore the structure of the significant effects. Cohen's f was calculated as an effect size for all F-values higher than 1.0 (Knudson, 2009; Ludbrook, 1998). All descriptive statistics are presented as means ± standard errors.

RESULTS

The analysis of variance revealed a significant main effect of the factor *Group* on estimated tilt angle, $F(1, 18) = 7.032$, $p = .016$, Cohen's $f = 0.625$, as well as a significant main effect of the factor *Rotation Axis* on estimated tilt angle, $F(1, 18) = 5.690$, $p = .028$, Cohen's $f = 0.562$. In addition, there was a significant two-way interaction effect of *Rotation Axis* × *Group* on estimated tilt angle, $F(1, 18) = 6.425$, $p = .021$, Cohen's $f = 0.597$. Surprisingly, there was neither a significant main effect of the factor *Visual Information* on estimated tilt angle, nor a significant two-way interaction effect of *Visual Information* × *Group* on estimated tilt angle (all $p > .30$). As a consequence, neither the two-way interaction effect of *Rotation Axis* × *Visual Information*, nor the three way-interaction effect of *Rotation Axis* × *Visual Information* × *Group* reached statistical significance (all $p > .40$).

In average, high-skilled gymnasts' estimated tilt angles were closer to the criterion angle of 45 degrees (-6.78 ± 2.13 degrees), as compared to low-skilled gymnasts (-14.75 ± 2.13 degrees). Estimated tilt angles were in average closer to the criterion angle of 45 degrees when participants rotated about the transverse axis (-9.65 ± 1.44 degrees), as compared to when participants rotated about the anterior-posterior axis (-11.88 ± 1.70 degrees). Differences between estimated tilt angles and the criterion angle of 45 degrees, however, differed as a function of *Rotation Axis* and *Group*. Low-skilled gymnasts exhibited larger differences between estimated tilt angles and the criterion angle about the anterior-posterior axis (-17.05 ± 2.41 degrees) when either compared to high-skilled gymnasts rotating about the transverse axis (-6.84 ± 2.03 degrees), high-skilled gymnasts rotating about the anterior-posterior axis (-6.71 ± 2.41 degrees), or low-skilled gymnasts rotating about the transverse axis (-12.45 ± 2.03 degrees). Figure 2 illustrates the differences between gymnasts' estimated tilt angles and the criterion angle of 45 degrees as a function of *Group* (high-skilled vs. low-skilled), *Rotation Axis* (transverse axis vs. anterior-posterior axis), and *Visual Information* (eyes open vs. eyes closed).

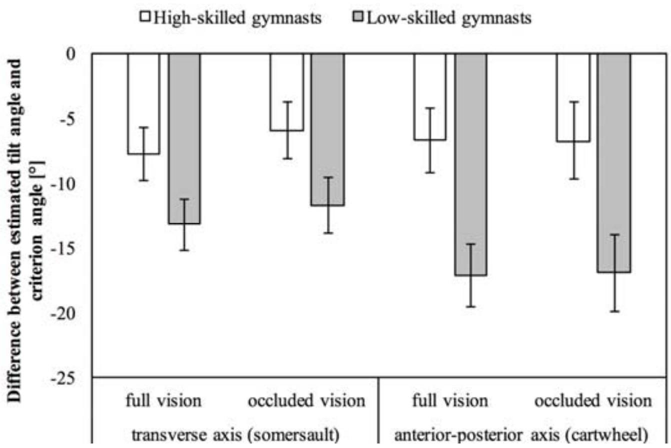


Figure 2. Differences between estimated tilt angles and criterion angle of tilt estimation task (means ± SE) in high-skilled gymnasts and low-skilled gymnasts as a function of *Visual Information* (full vision vs. occluded vision), and *Rotation Axis* (transverse axis vs. anterior-posterior axis). *Note:* Negative values indicate overestimation of body tilt (i.e., participant believes to be tilted further than she actually is).

DISCUSSION

High-skilled gymnasts are thought to exhibit a better ability for spatial orientation than low-skilled gymnasts (Sato et al., 2016). This superiority may stem from adaptations in the sensory motor system due to gymnasts' exposure to skill acquisition processes and/or motor training. The question is, however, which role visual information plays in the perception of spatial orientation in matters of gymnastics expertise and specific task demands? In this study, first, it should be confirmed that high-skilled gymnasts exhibit a better perception of body orientation than low-skilled gymnasts under changing task demands. Second, it should be determined if high-skilled gymnasts exhibit a better perception of body orientation than low-skilled gymnasts as a function of the availability of visual information.

Results revealed that high-skilled gymnasts exhibited higher estimated tilt angles, and thus a more precise estimation of body tilt, as compared to low-skilled gymnasts. This result is in line with theoretical approaches arguing that sport performers develop task-specific contingencies between sensory information and their corresponding motor actions during motor skill acquisition processes, and during motor training (O'Regan & Noë, 2001). The more performers are exposed to skill acquisition and/or motor training, the better their spatial orientation ability should become (von Lassberg et al., 2012). This result is also supported by findings from empirical studies showing that high-skilled gymnasts often outperform low-skilled gymnasts in spatial orientation tasks (i.e., Bringoux et al., 2000; Sato et al., 2016). An increased spatial orientation ability may result from an increased sensitivity in individual sensory systems, and/or from an optimized processing of interacting sensory information that is specific to the task demands (Davids et al., 2008; Latash, 2008).

Furthermore, it became obvious that estimating body tilt was dependent on rotation axis. Rotations about the transverse axis yielded slightly larger estimated tilt angles than rotations about the anterior-posterior axis. However, this aspect was most pronounced in low-skilled gymnasts rotating about the anterior-posterior axis, whereas high-skilled gymnasts exhibited no difference in estimating body tilt about the transverse axis, and the anterior-posterior axis. Low-skilled gymnasts and high-skilled gymnast's performance in the tilt estimation task could reflect their task-specific expertise in performing gymnastics skills with rotation about both rotation axis. While high-skilled gymnasts may have performed hundreds or even thousands of repetitions of skills with rotations about different body axis, the low-skilled gymnasts in this study had only basic gymnastics experience. In particular, the low-skilled gymnasts were exposed to approximately 30 hours of structured gymnastics training. This training comprised the acquisition of different gymnastics skills incorporating rotations about different body axes. However, skills with rotations about the transverse axis usually predominate level 1 gymnastics courses (i. e., forward and backward roll, handstand, handspring, somersault), compared to skills with rotations about the anterior-posterior axis (i. e., cartwheel, sideways roll). Thus, one could speculate that low-skilled gymnasts have accumulated more experience in performing skills incorporating rotations about the transverse axis as compared to skills incorporating rotations about the anterior-posterior axis, thereby exhibiting better tilt estimations when being rotated about the transverse axis.

In addition, and yet quite surprisingly, it became obvious that visual information was of minor influence in estimating body tilt. For example, when participants had their eyes open, the estimated tilt angle was similar to when participants wore a mask occluding visual information pickup. Nevertheless, it becomes also obvious, that the high-skilled gymnasts in this study were not able to perfectly solve the motor task, because high-skilled gymnasts tended to overestimate body tilt by approximately 6-7 degrees (i. e., the gymnasts thought that were tilted to 45 degrees, but were tilted only 38-39 degrees instead), independent of the availability of visual information, and independent of the rotation axis. In low-skilled gymnasts, this overestimation was even larger. The same overestimation occurred when no visual information was available, therefore supporting the argumentation of Naylor and McBeath (2009), that proprioceptive information, rather than visual information may cause this overestimation. Even low-skilled gymnasts with basic motor experience in gymnastics may not predominantly rely on visual information in the tilt estimation task of this study. However, relying on visual information for spatial orientation may thus be more specific to the task-demands. One could imagine for instance a standing scale in which the gymnast has to show a particular body posture on one leg with an inclined trunk while the other leg is raised and stretched to the back. This clearly brings about the challenge to keep the body in balance. In such a situation, visual information may facilitate task performance (Davlin et al, 2002; Latash, 2008). In tasks such as somersaults, visual information may be of high importance with regard to spatial orientation, because gymnasts might be able to anticipate landing already during the flight phase and therefore align their body posture and body orientation to perform an optimal contact with the landing mat in a given situation (Davlin et al., 2001; Luis & Tremblay, 2008).

There are some methodological limitations of this study and two specific aspects should be highlighted. First, gymnasts were placed in a human gyroscope in upright stance and they were asked to estimate body orientation when being rotated to 45 degrees. While a human gyroscope allows for precise and isolated rotation about the different body axes, one could still argue that motion in a human gyroscope (i.e., when being rather slowly rotated about the anterior-posterior axis) does only partly correspond to a ‘real' performance situation in artistic gymnastics (i.e., when actually performing a cartwheel). It could thus be of interest to contrast gymnasts' perception of spatial orientation as a function of differing demands when rotating about the same body axis under different rotation velocities and in different situations. Furthermore, a variety of gymnastics skills such as handstand are performed in a supported overhead position. Subsequent studies should therefore incorporate other experimental variations in their designs, such as comparing high-skilled gymnasts and low-skilled gymnasts when estimating for instance over-head body orientations with occluded vision. This could answer the question, if estimation of spatial orientation varies as an interaction of factors such as sport-specific expertise and (task-specific) rotation angle(s). Manipulating visuo-spatial perception could be one interesting methodological approach to address the aforementioned aspects (Allison, Howard, & Zacher, 1999).

Second, a sample consisting of former and current gymnasts as well as university students was recruited to participate in this study. Nevertheless, one could speculate that spatial orientation ability may develop specifically with regard to the demands in a particular sport, at a particular age, or with regard to factors such as rotational preference (Heinen et al., 2012; Kioumourtzoglou, Kourtessis, Michalopoulou, & Derri, 1998). While former gymnasts might already have made significant developments of (task-specific) spatial orientation ability early in their career, the effect of training on perception of spatial orientation might be different in university students because they are engaged in gymnastics at a later age. It could therefore be of interest to contrast spatial orientation ability in performers from different sports and on different expertise levels to answer the question if this ability is specific to the demands of different sports or if it is more a result of increased physical activity. In addition, it could be fruitful to contrast performers spatial orientation ability as a function of age, and exposure to a particular sport. In line with the aspects just mentioned, it could also be of interest to target perception of spatial orientation as a potential predictor for gymnastics talent, as well as a criterion in performance diagnostics programs (von Laßberg et al., 2015).

There are some practical consequences of this study, and one specific aspect should be highlighted. Results revealed that high-skilled gymnasts outperform low-skilled gymnasts in spatial orientation and that spatial orientation maybe specific to the amount of exposure to specific gymnastics training, while visual information plays a smaller role in estimating body tilt in a human gyroscope. In acrobatic sports such as artistic gymnastics, performers have to deal with a variety of different situations that could afford a different information pickup under changing environmental constraints and/or task-demands from trial to trial (Davids et al., 2008). It may thus be beneficial if high-skilled gymnasts are able to use information derived from the diverse sensory systems in a way that this information partly compensates each other when information from one or the other system is not available in a particular situation. This should not only facilitate estimating body orientation but it should also be beneficial in complex skill performance. Skill acquisition programs incorporating occlusion strategies may potentially account for the aforementioned aspect (Magill, 2011).

It is stated that an increased spatial orientation ability may result from an increased sensitivity in individual sensory systems, and/or from an optimized processing of interacting sensory information that is specific to gymnasts' experience with particular motor tasks and their corresponding demands.

REFERENCES

Allison, R. S., Howard, I. P., & Zacher, J. E. (1999). Effect of field size, head motion, and rotational velocity on roll vection and illusory self-tilt in a tumbling room. *Perception, 28*, 299-306.

Atkinson, G., & Nevill, A. M. (1998). Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. *Sports Medicine, 26*(4), 217-238.

Atkinson, G., & Nevill, A. M. (2001). Selected issues in the design and analysis for sport performance research. *Journal of Sports Sciences, 19*, 811-827.

Bersiner, K., & Heinen, T. (2016). Motor expertise and mental rotation performance in gymnastics. In T. Heinen, I. Čuk, R. Goebel, & K. Velentzas (Eds.), *Gymnastics performance and motor learning – principles and applications* (pp. 71-88). New York, NY: Nova Science Publishers Inc.

Bringoux, L., Marin, L., Nougier, V., Barraud, P.-A., & Raphel, C. (2000). Effects of gymnastics expertise on the perception of body orientation in the pitch dimension. *Journal of Vestibular Research, 10*, 251-258.

Bučar, M., Čuk, I., Pajek, J., Karacsony, I., & Leskošek, B. (2011). Reliability and validity of judging in women's artistic gymnastics at University Games 2009. *European Journal of Sport Science, 12*(3), 207-215.

Danion, F., Boyadjian, A., & Marin, K. (2000). Control of locomotion in expert gymnasts in the absence of vision. *Journal of Sports Sciences, 18*, 809-814.

Davids, K., Button, C., & Bennett, S. (2008). *Dynamics of skill acquisition: a constraints-led approach*. Champaign, IL: Human Kinetics.

Davlin, C. D., Sands, W. A., & Shultz, B. B. (2002). Influence of vision on kinesthetic awareness while somersaulting. *International Sport Journal, 6*(2), 172-177.

Davlin, C. D., Sands, W. A., & Shultz, B. B. (2001). The role of vision in control of orientation in a back tuck somersault. *Motor Control, 3*, 337-346.

Gautier, G., Thouvarecq, R., & Chollet, D. (2007). Visual and postural control of an arbitrary posture: the handstand. *Journal of Sports Sciences, 25*(11), 1271-1278.

Graziano, A. M., & Raulin, M. L. (2010). *Research methods. A process of inquiry* (7th ed.). Boston, MA: Allyn & Bacon.

Heinen, T., Jeraj, D., Vinken, P. M., & Velentzas, K. (2012). Rotational preference in gymnastics. *Journal of Human Kinetics, 33*, 33-43.

Heinen, T., Mandry, S., Vinken, P. M., & Nicolaus, M. (2013). Motor skill acquisition influences learners' visual perception in gymnastics. *Science of Gymnastics Journal, 5*(1), 19-28.

Hodges, N. J., & Williams, A. M. (Eds.) (2012). *Skill acquisition in sport. Research, theory and practice* (2nd ed.). New York, NY: Routledge.

Ito, Y., & Gresty, M. A. (1997). Subjective postural orientation and visual vertical during slow pitch tilt for the seated human subject. *Aviation, Space, & Environmental Medicine, 68*, 3-12.

Keetch, K. M., Schmidt, R. A., Lee, T. D., & Young, D. E. (2005). Especial skills: their emergence with massive amounts of practice. *Journal of Experimental Psychology: Human Perception and Performance, 31*(5), 970-978.

Kioumourtzoglou, E., Kourtessis, T., Michalopoulou, M, & Derri, V. (1998). Differences in several perceptual abilities between experts and novices in basketball, volleyball and water-polo. *Perceptual and Motor Skills, 86*, 899-912.

Knudson, D. (2009). Significant and meaningful effects in sports biomechanics research. *Sports Biomechanics, 8*(1), 96-104.

Latash, M. L. (2008). *Neurophysiological basis of movement* (2nd ed.). Champaign, IL: Human Kinetics.

Ludbrook, J. (1998). Multiple comparison procedures updated. *Clinical and Experimental Pharmacology and Physiology, 25*, 1032-1037.

Luis, M., & Tremblay, L. (2008). Visual feedback use during a back tuck somersault: evidence for optimal visual feedback utilization. *Motor Control, 12,* 210-218.

Magill, R. A. (2011). *Motor learning and control* (9th ed.). New York, NY: Mc-Graw Hill.

Moradi, J., Movahedi, A., & Salehi, H. (2014). Specificity of learning a sport skill to the visual condition of acquisition. *Journal of Motor Behavior, 46*(1), 17-23.

Naylor, Y. K., & McBeath, K. (2008). Gender differences in spatial perception of body tilt. *Perception & Psychophysics, 70*(2), 199-207.

O'Regan, J. K., & Noë, A. (2001). A sensorimotor account of vision and visual consciousness. *Behavioral and Brain Sciences, 24*, 939-1031.

Proteau, L. (1992). On the specificity of learning and the role of visual information for movement control. In L. Proteau, & D. Elliott (Eds.), *Vision and motor control* (pp. 67-103). Amsterdam: Elsevier Science Publishers B.V.

Raab, M., de Oliveira, R. F., & Heinen, T. (2009). How do people perceive and generate options? In M. Raab, H. Hekeren, & J. G. Johnson (Eds.), *Progress in brain research: vol. 174. mind and motion: the bidirectional link between thought and action* (pp. 49-59). Amsterdam, NL: Elsevier.

Sato, Y., Velentzas, K., & Heinen, T. (2016). Relationships between gaze behavior and motor behavior in complex aerial skills. In T. Heinen, I. Čuk, R. Goebel, & K. Velentzas (Eds.), *Gymnastics Performance and Motor Learning. Principles and Applications* (pp. 1-18). New York, NY: NOVA Science Publishers Inc.

von Gierke, H. E., & Parker, D.E. (1994). Differences in otolith and abdominal viscera graviceptor dynamics: implications for motion sickness and perceived body position. *Aviation, Space, and Environmental Medicine, 65*, 747-751.

von Lassberg, C., Beykirch, K., Campos, J. L., & Krug, J. (2012). Smooth pursuit eye movement adaptation in high level gymnasts. *Motor Control, 16*, 176-194.

von Laßberg, C., Beykirch, K. A., & Campos, J. L. (2015). Comparing vestibulo-ocular eye movement characteristics with coaches' rankings of spatial orientation aptitudes in gymnastics. In T. Heinen (Ed.), *Advances in visual perception research* (pp. 61-81). New York, NY: Nova Publishers Inc.

Wade, M. G., & Jones, G. (1997). The role of vision and spatial orientation in the maintenance of posture. *Physical Therapy, 77*(6), 619-628.

Williams, A. M., & Ericsson, K. A. (2005). Perceptual-cognitive expertise in sport: some considerations when applying the expert performance approach. *Human Movement Science, 24*(3), 283-307.

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