MOVEMENT REGULATION IN DISMOUNTS ON THE BALANCE BEAM

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Abstract

In artistic gymnastics, the apparatus structure is considered an essential constraint in regulating gymnastic skill performance under an operating coupling between perception and action. The question arises of how such regulation processes generalize within gymnastic skills with a similar movement goal but a different structure. Therefore, this study aimed to analyze how a particular environmental constraint (space available on the balance beam) regulates gymnasts' performance in skills with a similar movement goal but a different movement structure. Female gymnasts were asked to perform the round-off and the handspring as dismounts on the balance beam in two conditions (baseline vs. reduced space available). Gymnasts exhibited differences in foot positioning between experimental conditions. For both skills, the most significant part of regulation occurred between the starting point and the first step, and a small part of regulation occurred between the first step and the placement of the hands. For the round-off, another small regulation also occurred between the placement of the second hand and landing on the mat; there was virtually no regulation between the placement of the hands and landing on the mat in the handspring. It is concluded that, for gymnasts, adapting to varying constraints from trial to trial can be seen as an essential skill. Implementing these constraints into practice schedules may help develop a broad range of regulation strategies.

Keywords: *perception-action coupling, environmental constraints, handspring, round-off.*

INTRODUCTION

Skills in artistic gymnastics are performed on fixed and stationary apparatuses (Arkaev & Suchilin, 2004; FIG, 2022a; Turoff, 1991). The apparatus structure is considered an essential constraint in regulating gymnastic skill performance (Barreto et al., 2021; Bradshaw, 2004; Davids et al., 2008; Raab, de Oliveira, & Heinen, 2009). Evidence suggests a close and continuous coupling between perception and action when regulating the state of motion in relation to the environment and the movement goal (Cornus et al., 2009; Fajen et al., 2009; Warren, 2006). However, there are various skills in gymnastics, and the question arises of how such regulation processes generalize within gymnastic skills with a similar movement goal but a different movement structure. Therefore, this study aimed to analyze how a particular environmental constraint (the space available on the balance beam) regulates gymnasts' performance in two skills with a similar movement goal but a different movement structure. The round-off and the handspring performed as dismounts on the balance beam were chosen because both skills share a similar movement goal (i.e., performing a somersaulting motion after hand support to landing upright on the landing mat). Still, both have a different structure (Turoff, 1991): while the round-off incorporates a half-turn about the longitudinal axis during the support and flight phases, the handspring does not.

Theoretical approaches and empirical evidence suggest that skill acquisition involves developing specific contingencies between sensory information and a particular skill's movement requirements (O'Regan & Noë, 2001; O'Regan, 2022). There are various information sources available when performing a particular skill. Yet, the aforementioned contingencies are thought to be developed towards the information that can directly guide actions (Raab et al., 2009; Withagen & Michaels, 2005). Consequently, expert performers can pick up task-relevant information from the environment and use it to regulate their movements to achieve a particular movement goal (Bradshaw & Sparrow, 2001; Bradshaw, 2004; Warren, 2006). For example, when gymnasts move, they may predominantly utilize the visual system to pick up distal information from the environment (i.e., apparatus structure), thereby regulating the current state of motion by exerting forces on the environment when being in contact with a supporting surface (Bardy & Laurent, 1989; Barreto et al., 2020, 2021; Bradshaw & Sparrow, 2001; Haigis, & Schlegel, 2020; Larsen et al., 2016; Lee et al., 1982; Mester, 2000; Latash, 2008; Montagne et al., 2002).

For instance, Bradshaw (2004) analyzed gymnasts' motor behavior during round-off entry vaults. Among other parameters, the onset of visual control was calculated from the run-up kinematics. The author could show that skilled gymnasts use visual information to control the approach run during round-off entry vaults. It could be concluded that using vision in the approach run in gymnastics vaulting enables the gymnast to make corrections from one step to the next to precisely hit the springboard at the end of the approach run. In a similar study, Heinen et al. (2011) had female gymnasts perform handsprings on the vault while manipulating the position of the springboard. The authors could, for instance, show that feet positioning during the approach run and take-off varied predominantly as a function of the position of the springboard, thereby supporting the notion of a visually-driven regulation of the approach run based on the perception of the position of the springboard. Barreto et al. (2021) measured gaze behavior and movement kinematics of gymnasts with different expertise during the approach run and take-off when performing two complex gymnastics skills (double somersault with half twist performed on the mini trampoline either with or without the vaulting table). Results revealed that gaze behavior mainly differed between skills for elite gymnasts, and take-off velocity differed between skills for both groups. It was concluded that differing constraints during skill execution (i.e., the presence or absence of a vaulting table) influenced motor behavior. At the same time, its influence on gaze behavior depended also on gymnasts' expertise.

When performing gymnastics skills, gymnasts experience natural variations in movement execution from trial to trial (Bradshaw et al., 2010; Hiley et al., 2013). This aspect implies the need to gather information from the environment concerning one's own position, orientation, and state of motion to regulate the ongoing motor skill toward the movement goal within these constraints (Davids et al., 2008; Warren, 2006). In this context, Heinen (2017) studied, for instance, gymnasts' movement regulation when performing cartwheels on a spring floor while manipulating the space available to perform these cartwheels. Results revealed that gymnasts accommodated the manipulated space and that the distribution of regulation in the three cartwheels differed between manipulation conditions. It was speculated that gymnasts regulate motor skills in a stationary environment in a way that accommodates the current configuration of constraints. Heinen et al. (2015) asked female gymnasts to perform two different gymnastics mounts after a short run-up and a reactive leap while apparatus constraints were manipulated (i.e., springboard position). It was found that the hurdle's distance and the feet' placement on the springboard varied between the two gymnastics mounts but not as a function of manipulation of the springboard position. It was concluded that gymnasts show different movement behaviors in tasks with similar movement goals but differing dynamics.

However, there are various skills in gymnastics, and the question arises of how such regulation processes generalize to gymnastic skills with a similar movement goal but a different structure. For example, the balance beam in gymnastics is five meters long, ten centimeters wide, and elevated to a height of 1.25 meters (FIG, 2022b). When gymnasts perform a dismount, they may use a maximum space of 5 meters from one edge to the other edge on the beam to fit in preparatory movement parts such as a run-up or support of the intended dismount. However, the starting point for the dismount usually depends on the previously performed skill, so there is often a natural variation in the execution of dismounts, which demands an adapted regulation from trial to trial (Heinen, 2017; Hiley & Yeadon, 2015). Likely, the relation between the gymnasts' current position and the space available on the balance beam is an essential environmental constraint and might provide relevant information for this regulation (Davids et al., 2005; 2008). Nevertheless, the question arises of how gymnasts regulate dismounts with a similar movement goal but a different structure (Potop & Cretu, 2015; Potop et al., 2022).

For example, a round-off dismount has a similar movement goal as a handspring dismount on the balance beam (i.e., performing a somersaulting motion after hand support to landing in an upright position on the landing mat) but a different structure: when performed from a standing position, gymnasts lunge forward and place their hands toward the end of the beam before performing a somersaulting movement (Turoff, 1991). However, while the round-off incorporates a half-turn about the longitudinal axis during the support and flight phases, the handspring does not (see Method section). Thus, the half-turn in the round-off might enable gymnasts to pick up distal visual information from the landing area during the support phase, which in turn might allow them to regulate the round-off based on current visual information pickup also during the support phase (Davlin et al., 2001; Geiblinger, & Dowden, 2015). This aspect could affect the landing position in the round-off, while this may not be the case in the handspring due to missing visual information pickup from the landing mat during the support phase.

Following the argumentation above, this study aimed to analyze to what extent a particular environmental constraint (i.e., space available on the balance beam) regulates gymnasts' performance in two skills that have a similar movement goal but are different in movement structure, namely the round-off and the handspring as dismounts on the balance beam. Skilled gymnasts were asked to perform the two dismounts under two conditions (baseline vs. reduced space available). The absolute positions of gymnasts' contact points on the beam and the landing mat were analyzed. It was hypothesized that regulation during the initial phase of the dismounts varied predominantly as a function of the space available on the balance beam (Heinen, 2017). However, regulation during the support and flight phases was expected to differ predominantly between the two skills due to their structural differences during the support phase (Turoff, 1991).

METHODS

N = 12 female gymnasts participated in this study. Their age was 11.42 years on average. The gymnasts reported an average practice amount of two to three times a week, and all started gymnastics from a young age, mainly before the age of five. All of them reported doing gymnastics in the german "Leistungsklasse 2" or "Leistungsklasse 4" (DTB, 2023). Every participant reported familiarity with the two experimental tasks (see below). The gymnasts perceived the tasks as easy, so they were considered experts, particularly given their young age (Chi, 2006). The participating gymnasts and their parents were informed about the general procedure of the study, and the parents gave their written consent before the beginning of the study. The study was carried out according to the ethical guidelines of the university's local ethics committee.

Experimental tasks. Gymnasts were asked to perform two different experimental tasks. The first experimental task was a round-off as a dismount on the balance beam. In the second task, the participants had to perform a handspring as a dismount on the balance beam (Turoff, 1991; Figure 1). The balance beam was arranged and adjusted to match the competition guidelines for Women's Artistic Gymnastics (FIG, 2022a). For later analysis, the reference point was defined as the horizontal position of the orthogonal projection of the leading edge of the balance beam. Gymnasts' individual starting points were marked with white tape. From an upright stance, the gymnasts took one step toward the end of the beam, then put their hands on the beam for support, performed the corresponding somersaulting motion, and landed with both feet on the landing mat. Both skills were to be performed in a baseline condition equivalent to each gymnast's starting point. In the second condition (experimental condition), the space available on the balance beam was reduced by 20 centimeters in relation to the individual starting point in the baseline condition. The starting position in the experimental condition was also marked with white tape for orienting purposes.

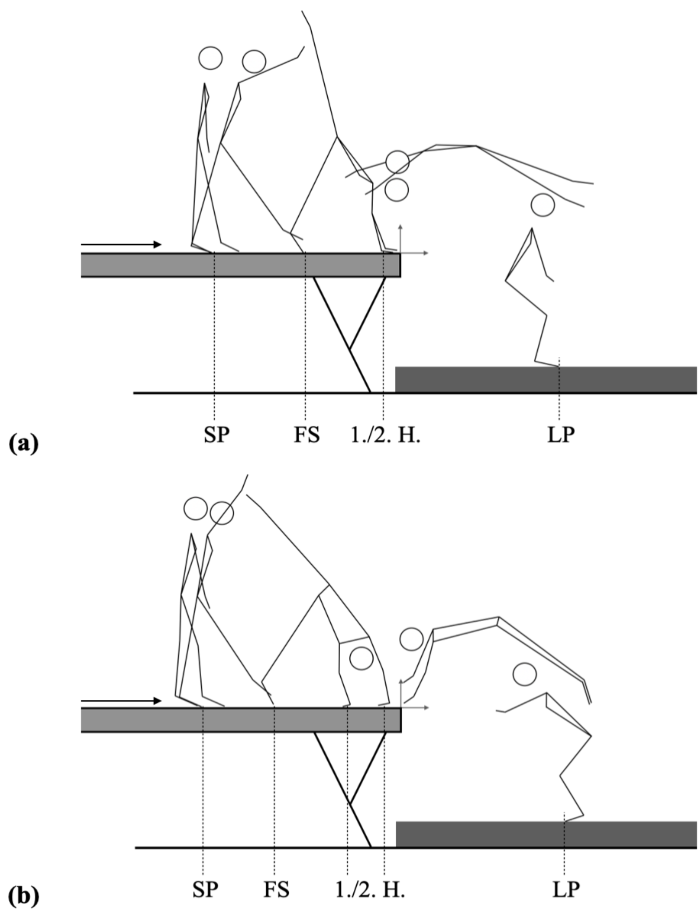

Figure 1. Stick-figure sequences of the handspring (a) and round-off (b) as dismounts on the balance beam (*Note:* SP = starting position, FS = first step, 1./2. H = first and second hand, LP = landing position).

Movement Analysis. Gymnasts' performances were videotaped using a SONY FDR-AX53 video camera. A temporal resolution of 50 Hz was seen as sufficient because only spatial parameters with low regulation velocity were analyzed. A spatial resolution of 1920 x 1080 pixels was also considered sufficient because the space required to perform the experimental tasks was approximately 2.50 meters. The camera was placed approximately 15 meters away from the balance beam. The optical axis was arranged orthogonal to the apparatus axis of the balance beam and aligned towards the leading edge of the balance beam. Camera zoom was adjusted to ensure that the complete performance (starting position to landing) could be recorded with maximized resolution. The camera was calibrated to the gymnasts' movement plane with the help of a 4-meter calibration stick. The horizontal coordinates of the toes of the feet during the starting position, the first step, and the landing on the mat as well as the mid-point of the hands during support on the balance beam (Figure 1), were analyzed using the free video analysis tool Tracker (ver. 6.0.10; https://physlets.org/tracker/). The coordinate origin was set at the intersection between the leading edge and the surface level of the balance beam (0.00 meters in the horizontal and vertical directions). From the performances of each gymnast in each experimental condition, the average values for the aforementioned horizontal coordinates were calculated over all trials and used for further statistics calculations.

Relative differences between contact points and experimental conditions were calculated to estimate movement regulation in both experimental tasks.

The study was conducted in three phases. In the first phase, the gymnasts arrived at the gymnasium with their coaches and parents. The gymnasts, the coach, and the parents were informed about the purpose of the study and the experimental task. After providing consent, the gymnasts had time to warm up for about 20 minutes and to familiarize themselves with the experimental task. In the second phase, the data acquisition took place. The gymnasts' task was to do a round-off and a handspring as dismounts on the balance beam. The order of the tasks was randomized between gymnasts. Both skills were performed three times in both conditions (baseline vs. experimental). All in all, each gymnast completed twelve trials. In the baseline condition, the gymnasts began to dismount from their individual starting positions. In the experimental condition, the space available on the balance beam (i.e., the distance between the individual starting position and the end of the beam) was reduced by 20 centimeters. After data acquisition and in the third phase of the study, the gymnasts were debriefed

The significance level was set at alpha = 5% before data analysis. Separate paired samples *t*-tests were calculated, and Holms correction was applied to control for familywise error rate (Knudson, 2009). The average positions of the toes and the hands (see method section) were used as the dependent variable. We conducted an additional descriptive analysis of relative differences between contact points and between experimental conditions as an indicator of movement regulation.

RESULTS

It was hypothesized that regulation during the initial phase of the dismounts varied predominantly as a function of the space available on the balance beam. However, regulation during the support and flight phases was expected to differ predominantly between skills due to their structural differences during the support phase. According to the *t*-tests, there were significant differences between experimental conditions in the starting point ($t(11) = 10.75$, Cohen's $d = 3.10$), the first step ($t(11) = 5.17$, Cohen's $d = 1.49$), and in the positioning of the first hand ($t(11) = 4.49$, Cohen's $d = 1.30$) for the round-off, and in the starting point ($t(11) = 2.78$, Cohen's $d = 0.80$), the first step ($t(11) = 10.14$, Cohen's $d = 2.93$) the positioning of both hands (first hand: $t(11) = 4.07$, Cohen's $d = 1.17$, second hand: $t(11) = 5.28$, Cohen's $d = 1.53$), and during landing for the handspring ($t(11) = 2.41$, Cohen's $d = 0.70$; all $p < .05$; Figure 2).

Gymnasts performed both the round-off and the handspring in both experimental conditions. While in the round-off, the second hand and the landing on the mat were realized on the same spot in both experimental conditions, there were differences for the handspring in all contact points in both experimental conditions. Considering the relative differences between contact points and between experimental conditions as an indicator of movement regulation, the following results emerged for the round-off: Approximately 45.8% of regulation occurred between the starting point and the first step. In comparison, 29.4% occurred between the first step and the placement of the first hand, and 11.8% occurred between the placement of the first and second hand. The remaining 13.1%

occurred between the placement of the second hand and the landing on the mat. For the handspring, 78.3% of regulation occurred between the starting point and the first step, and 21.3% of regulation occurred between the first step and placement of the first and second hand. In comparison, only 0.4% of regulation occurred between the placement of the second hand and landing on the mat.

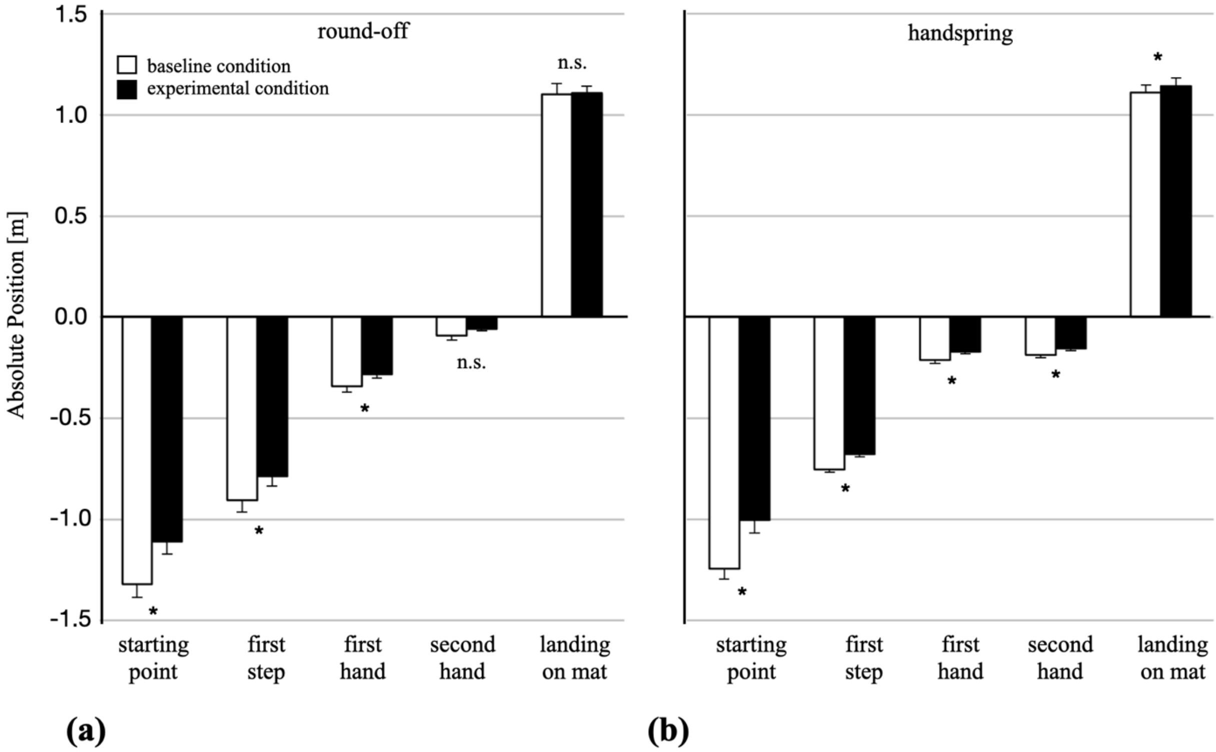

*Figure 2***.** Absolute horizontal positioning during the different contact points when performing the round-off (a) and the handspring (b) as dismount on the balance beam. *Note:* The coordinate origin (0.0 meters) was set at the intersection between the balance beam's leading edge and the surface level. * indicates a significant difference between experimental conditions (p < 5%).

DISCUSSION

This study aimed to analyze to what extent a particular environmental constraint (i.e., space available on the balance beam) regulates gymnasts' performance in two skills that have a similar movement goal but are different in movement structure, namely the round-off and the handspring as dismounts on the balance beam (Turoff, 1991). It was hypothesized that regulation during the initial phase of the dismounts varies predominantly as a function of the space available on the balance beam (Heinen, 2017). However, regulation during the support and flight phases was expected to differ predominantly between skills due to their structural differences during the overhead phase (Turoff, 1991).

The following pattern of results emerged: Gymnasts exhibited differences in foot positioning between experimental conditions in the starting point, the first step, and in the positioning of the first hand for the round-off, and in the starting point, the first step, the positioning of both hands and during landing for the handspring. For both the round-off and the handspring, the most significant part of regulation occurred between the starting point and the first step, and a small part of regulation occurred between the first step and the placement of the hands. For the round-off, another part of regulation also occurred between the placement of the second hand and landing on the mat; there was virtually no regulation between the placement of the hands and landing on the mat in the handspring.

When being in contact with support surfaces, gymnasts can regulate the current state of motion by exerting forces on the environment based on picked-up information from the environment (Lee et al., 1983; Mester, 2000). While a round-off incorporates a half-turn about the longitudinal axis during the support and flight phases, the handspring does not. The results of our study thus seem to confirm that the half-turn in the round-off might enable gymnasts to pick up distal visual information from the landing area during the support phase, which in turn might allow them to regulate the round-off during the support and toward the landing phase (Davlin et al., 2001; Geiblinger, & Dowden, 2015). This regulation leads to a stable landing position between experimental conditions. However, this is not the case for the handspring due to missing visual information pickup from the landing mat during the support phase.

Gymnasts were asked to perform a handspring and a round-off as dismounts on the balance beam because both skills have the same movement goal but a different movement structure. In competitive gymnastics, these are two relatively simple tasks for advanced gymnasts. The question arises of how movement regulation strategies generalize to gymnastics skills performed under other environmental or task constraints (Barreto et al., 2021; Heinen et al., 2017). Even though we found differences in regulation between the round-off and the handspring as dismount on the balance beam, a particular regulation during the support phase of the round-off might not be necessary given the relatively large landing area. Nevertheless, the landing area is marked with white tape in gymnastics vaulting. One could speculate how this tape might regulate gymnasts' movement performance because landing outside the marked area leads to deductions in judges' scores. Placing the feet and hands on the balance beam results from moving the body's limbs. Yet, in gymnastics, specific angles between limbs are subject to judging, and it might be questionable in further research whether different regulation strategies could potentially impair the technical performance of the skill at hand. Further studies could also assess movement regulation in the same task performed with differing dynamics, assuming that different dynamics could afford a different regulation to achieve the same movement goal (i.e., a round-off performed as a dismount on the balance beam from a standing position versus a round-off performed as a dismount on the balance beam from a short run-up).

Gymnastics involves skills with unique technical requirements (Sands et al., 2003). Thus, for gymnasts, adapting to varying constraints from trial to trial is an essential skill (Schöllhorn et al., 2012). Implementing these varying constraints into practice schedules could be fruitful in developing a broad range of regulation strategies. This idea might enable gymnasts to perform with high stability in different practice and competition situations

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