THE SIMULATION OF COACHES' MANUAL GUIDANCE TECHNIQUES DURING THE PERFORMANCE OF A GYMNASTIC SKILL

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Original article

Abstract

The aim of this study was to explore the effect of different manual guidance techniques on performance-related variables of a backward salto. We simulated a backward salto by means of a computer model. Changes in performance-related variables were calculated as a result of isolated and combined hand applications. We created seven conditions that varied in angle and amount of added forces, the location of the added forces, and the activation time of the added forces, resulting in 231 simulation runs. We found that the most effective guidance technique was situation specific, because reducing or increasing the gymnast's rotation speed and adding movement height are interdependent. To accompany a movement, it is possible to use an isolated hand application at the iliac crest during the flight phase of the salto, but for stronger support it is necessary to apply a guidance technique immediately at takeoff. When using a guidance technique that involves both hands, it seems that the timing of the hand application is more critical than the angle or amount of added force a coach uses.
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Keywords: *Sport, Computer Model, Hand Application, Performance Effects.*

INTRODUCTION

In the current study, we wanted to analyze the effects of a specific manual guidance technique on the performance of a backward salto. In the research field of sports simulation a variety of models have been developed and the literature reveals a number of different aims (for a review see Chow & Knudson, 2011). Much of the research has to do with identifying optimal sports techniques or optimal sports movements (Mkaouer, Jemni, Amara, Chaabèn, & Tabka, 2012; Sheets & Hubbard, 2009), often focusing on the outcome (Hiley & Yeadon, 2008). Other studies have been aimed at optimizing the equipment used (Cagran, Huber, & Müller, 2010; Gu & Li, 2007), evaluating models against real performance (Sheets & Hubbard, 2008), or predicting new techniques (Čuk, Atiković, & Tabaković, 2009; Heinen, Jeraj, Vinken, Knieps, Velentzas, & Richter, 2011). The aim of the current study was to evaluate the effects of various techniques for manually applying additional force on movement performance in gymnastics (manual guidance), in particular during the backward salto.

Manual guidance is functional when the gymnast has already learned a movement and is potentially able to perform it but needs support in a slight way to optimize the movement or to lower the risk of injury when performing the movement (Sands, 1996). Manual guidance results in a better movement performance (Armstrong, 1970). In gymnastics, this approach is commonly used in most of the methodical steps of a complex gymnastic technique to prevent injuries and to offer the athlete a secure feeling (Arkaev & Suchilin, 2007). In the backward salto, guidance techniques that usually involve an isolated hand application at the thigh or iliac crest or one that combines hand applications at the two locations (Heinen, Vinken, & Ölsberg, 2010).

Studies revealed that manual guidance influences psychological aspects of movement performance, such as fear of injury and self-efficacy (Heinen, Pizzera, & Cottyn, 2009). The authors of this study examined the effects on performance of the fear of injury and level of self-efficacy in different methodical steps of two gymnastic techniques on the balance beam, with and without manual guidance of the coach. Guidance, in this study, led to enhanced self-efficacy and changes in the level of fear of injury, but the strength of the effect depended on the complexity and the biomechanical demands of the movement. In another study, a coach used different guidance techniques for the same gymnastic movement (Heinen, Vinken, & Ölsberg, 2010) while kinematic analyses were conducted. It was shown that there were kinematic effects on performance when a coach guided a complex gymnastic technique with different guidance techniques. The effects were significant in several kinematic parameters; for example, the angular momentum decreased and the flight time increased when a coach supported the performance of a round-off with a backward salto with hand application at the iliac crest and thigh.

The current literature leads us to believe that there is a link between manual guidance and performance (Heinen, Vinken, & Ölsberg, 2010), but the details of this relationship are still unclear. Movement input and movement output can be observed and estimated, but the interaction between these entities has not been clarified. Additionally and from a more pragmatic point of view, it has often been reported in continuing education programs and in daily training situations that manual guidance is a skill that has to be continually practiced (Sands, 1996) and it has influence on the risk of injury (Sands, McNeal, Jemni, & Penitente, 2011). Thus, even though coaches are trained in guiding a gymnastic element, the manual guidance may not be optimal in every case, and the output (the performance) may not be enhanced.

In sum, a simulation of the backward salto and different specific guidance techniques should help clarify the relation between input (hand applications) and the resulting movement (kinematic parameters). From the existing simulation models and with the help of a biomechanist, we determined that the following factors are the most important when guiding the backward salto (Yeadon, 1990; Yeadon & Morlock, 1989): timing, duration, magnitude, and direction. Timing refers to when in the movement manual guidance is applied. Duration refers to the length of application, magnitude to the amount of force applied, and direction to whether the angle of force is positive (cranial) or negative (caudal). We expected that the different force inputs for an optimal hand application to support the gymnast’s body are very small in terms of timing, direction, duration, and magnitude for the resulting movement. Furthermore, we expected that a suboptimal use of one input factor should be compensated for by a second input factor, but also that a suboptimal use of one input factor could lead to a worse movement performance.

METHODS

Data collection. Data was collected in collaboration with a regional-level female German gymnast (23 years old, 1.59 m, 50 kg) during training, while she performed single backward saltos from stand to stand (10 trials). The gymnast was videotaped after she gave informed consent. The data collection was carried out according to the ethical guidelines of the local university. The performances were videotaped using a digital video camera (Casio EX-FH100) operating at 120 frames/s (spatial resolution: 640 × 480 pixels). The camera was placed approximately 5 m from the gymnast and orthogonal to the movement plane and was calibrated with a 2 × 2 m calibration square.

A national-level gymnastics coach was asked to select the best performance of the gymnast from the videotaped sequences of the 10 salto trials. The gymnast's best performance was digitized using the software Simi Motion (Simi Reality Motion Systems, 2012). The two-dimensional (2D) coordinates of the body landmarks were reconstructed from the digitized data using the direct linear transformation algorithm (Shapiro, 1978). A digital filter was applied for data smoothing. A mean temporal error of ± 0.0033 s and a mean spatial error of ± 0.008 m were calculated from the data. The corresponding joint angle histories were calculated from the 2D coordinates of the segment endpoints.

To estimate the additional forces a coach can create when guiding the salto manually, we measured the maximum isometric force with a force-measuring device in body and ankle positions such as if the coach would guide the movement. Based on the measured maximal isometric force with both hands of 150 N, we defined three different force amplitudes for the simulations: 50 N, 100 N, and 150 N.

Simulation model. We used a computer simulation model based on 16 body segments, developed to simulate skills in gymnastics was used (Heinen et al., 2011). The 16 segments represented two feet, two shanks, two thighs, the hip and lower trunk, the middle trunk, the upper trunk, two upper arms, two forearms, two hands, and the gymnasts' head. Fifteen joints connected the segments. Since the input data was generated from 2D body landmark data, the computer simulation model was used in its 2D version. Therefore, the motions of both feet, both shanks, both thighs, both upper arms, both forearms, and both hands, respectively, were linked, so that the two segments (one from each body side) were treated as one segment.

The model was furthermore customized to the real gymnast through the determination of subject-specific inertial parameters (Yeadon, 1990, Yeadon & Morlock, 1989). These input parameters comprised segmental inertial parameters and the gymnast's performance in terms of calculated and smoothed angle–time histories. Initial conditions consisted of the gymnast's vertical and horizontal release velocities of the center of mass and the angular velocity about the transverse axis at release. The Kutta–Merson algorithm was used with a frame rate of 300 Hz and a variable integration step size of 0.00167 s to solve the model's motion. Output from the model comprised the resulting motion of the gymnast as well as the angular momentum and the height of flight (Gervais & Dunn, 2003). A three-dimensional computer graphics model of the human body was used to illustrate the model output after the motion was solved (see Figure 1).

Procedure. The present study consisted of two phases. In the first phase, the backward salto of the regional gymnast was simulated. All relevant parameters were integrated in the model, namely, the gymnast's angle–time histories, the gymnast's vertical and horizontal velocity at release, and the angular velocity about the transverse axis at the release.

In the second phase, the simulated performance was estimated from the resulting motion as well as from the height of flight and the angular momentum of the model for each simulated variant of the different hand applications. The simulation variants were (1) isolated hand application simulations in four conditions (n = 84 simulation runs) and (2) combined hand application simulations in three conditions

(n = 147 simulation runs). The conditions were defined as follows:

(1a) Isolated hand application at the *thigh* with different angles ranging from -45° (caudal direction) to +45° (cranial direction) in 15° steps with three different force amplitudes (50N, 100N, 150N), resulting in 7 × 3 = 21 simulation runs. The forces were applied from 0 to 0.23 s during each simulation run (see Figure 2a).

(1b) Isolated hand application at the *iliac crest* with different angles ranging from -45° to +45° in 15° steps with three different force amplitudes (50N, 100N, 150N), resulting in 7 × 3 = 21 simulation runs. The forces were applied from 0 to 0.23 s during each simulation run (see Figure 2b).

(1c) Isolated hand application at the iliac crest as in condition 1b, but with *longer* force activation, resulting in 7 × 3 = 21 simulation runs. The forces were applied from 0 to 0.33 seconds during each simulation run (longer activation with same magnitude; see Figure 2b).

(1d) Isolated hand application at the iliac crest as in conditions 1b and 1c, but with *later* activation, resulting in 7 × 3 = 21 simulation runs. The forces were applied from 0.10 to 0.33 s during each simulation run (see Figure 2b).

The conditions comprising combined hand applications were simulated with constant force amplitude of 100 N and a constant activation of the hand application at the thigh. The conditions were defined as follows:

(2a) *Simultaneous* activation of the iliac crest and thigh hand application with different angles ranging from -45° to +45° in 15° steps for both hands, resulting in 7 × 7 = 49 simulation runs.

(2b) *Longer activation* of the iliac crest and normal activation of the thigh hand application with different angles ranging from -45° to +45° in 15° steps for both hands, resulting in 7 × 7 = 49 simulation cycles.

(2c) *Later activation* of the iliac crest and normal activation of the thigh hand application with different angles ranging from -45° to +45° in 15° steps for both hands, resulting in 7 × 7 = 49 simulation runs.

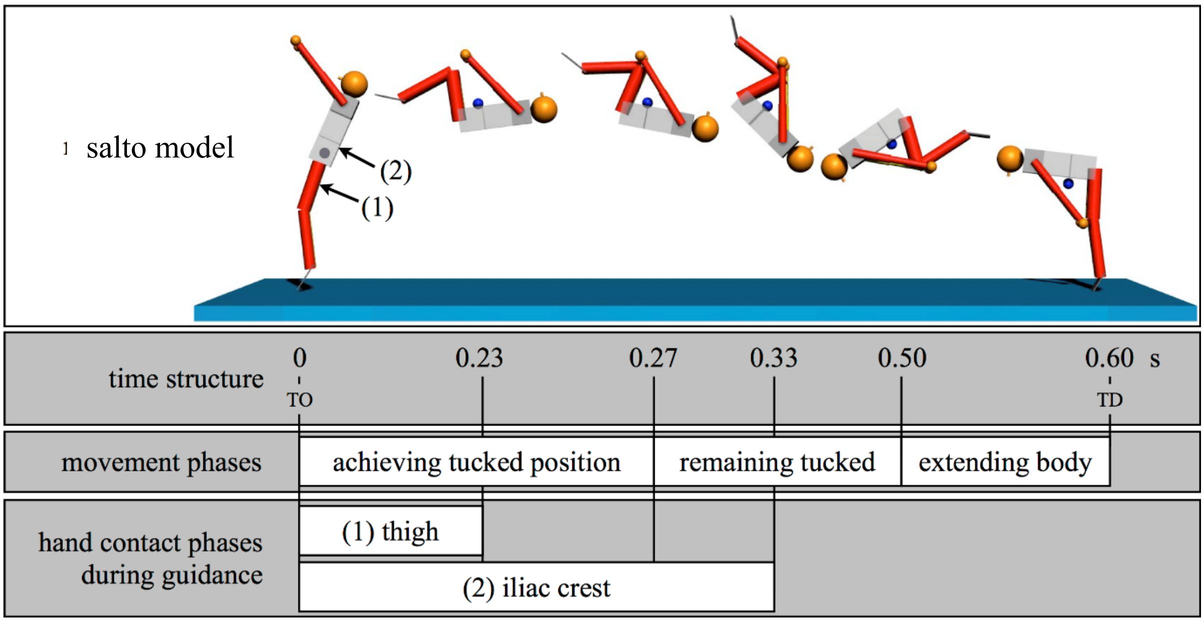

Figure 1. Illustration of a simulated backward salto from takeoff (TO) to touchdown (TD), together with its corresponding movement phases and hand contact phases on (1) thigh and (2) iliac crest, during which guiding forces were applied. *Note: For illustration purposes, the time course is not true to scale.*

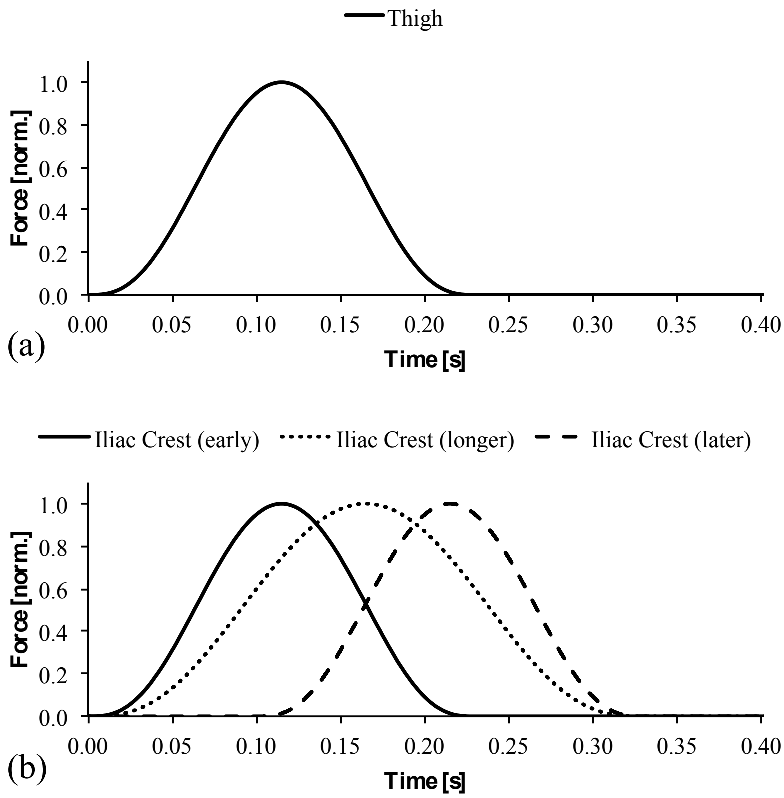

Figure 2. Normalized force–time histories when applying different guiding forces to the backward salto model: (a) hand contact on thigh, (b) hand contact on iliac crest (solid line: early activation, dotted line: longer activation with same magnitude, dashed line: later activation).

RESULTS

Original performance of the backward salto

Integrating the angle–time histories, the vertical and horizontal velocity at takeoff, as well as the angular velocity about the transverse axis at takeoff into the present model led to a successful simulation of the backward salto (see Figure 1). The salto angle was calculated from the original performance of the gymnast's salto as well as from the salto performance of the simulation model. Additionally, the time of flight was calculated. We evaluated the model by comparing the time courses of the two angles. The simulated salto rotation angle matched the gymnast's salto rotation angle within 1.8° root mean square difference (cf., Hiley & Yeadon, 2007). The flight time matched the original performance within 0.0033 s.

Effects of isolated hand applications

For a detailed illustration of the estimated angular momentum and height of flight output, see Figure 3. Taken together, the results of the simulation conditions (1a–d) are as follows: Condition 1a: The strongest effect on angular momentum was estimated for the simulation of an isolated hand application at the thigh with an optimum angle of about -30°. The strongest effect on height of flight was estimated with an optimum angle of about +15°. Condition 1b: The strongest effect on height of flight was estimated for the simulation of an isolated hand application at the iliac crest with an optimum angle of about +30°. Simultaneously, this +30° application led to a reduction of the angular momentum. Condition 1c: The differentiation between the contact times of the simulated hand applications showed only marginal differences between early and short hand contact and longer hand contact. However, longer isolated hand contact on the iliac crest had a slightly stronger effect on reduction of angular momentum. Condition 1d: The simulation showed only a weak effect on angular momentum and on height of flight for the isolated hand application at the iliac crest with a later activation.

Effects of combined hand applications

For a detailed illustration of the estimated output angular momentum and height of flight, see Figure 4. Taken together, the results of the simulation conditions (2a–c) are as follows: Condition 2a: The simulation showed a small effect on angular momentum. Condition 2b: Simulating a longer contact time on the iliac crest showed no differences on height of flight. However, there was a small effect on angular momentum, slightly higher than in condition 2a. Condition 2c: Simulating a later activation of force applied on the iliac crest showed almost the same effect on angular momentum and a small effect on height of flight as compared to the previous conditions.

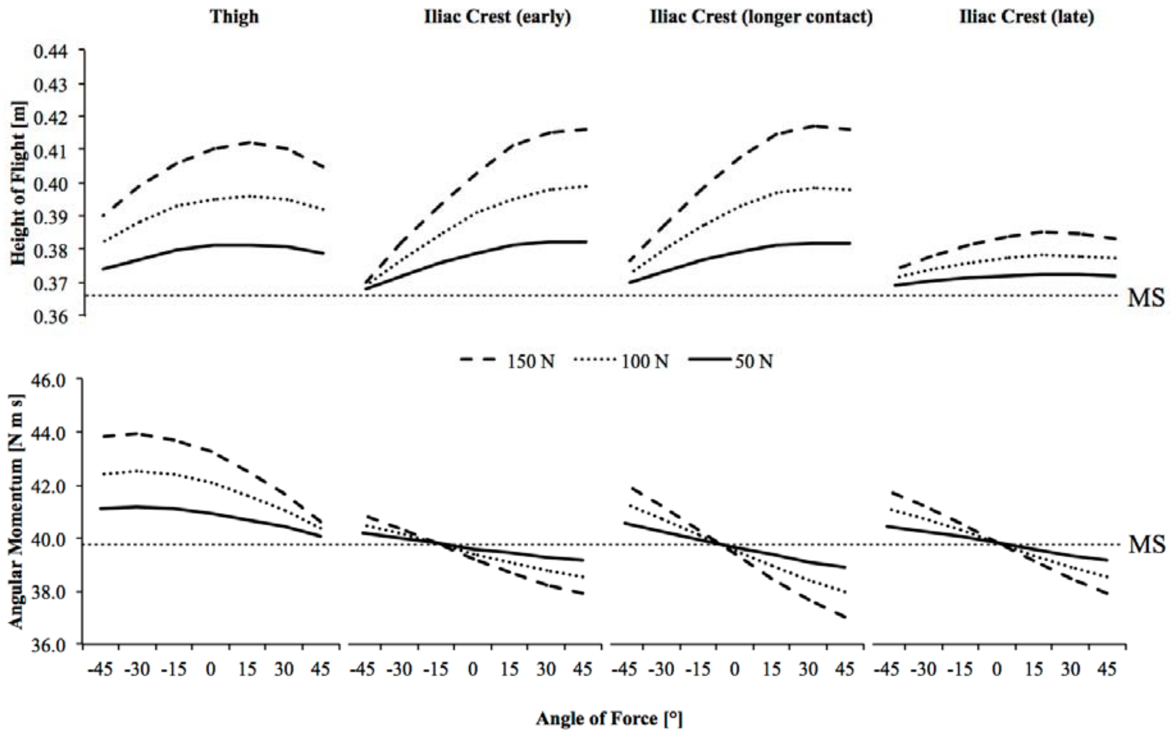

Figure 3. Isolated effects (conditions 1a–d) of applying guiding hand contact forces in different directions and with different magnitudes on angular momentum and height of flight of the backward salto. *Note: A negative angle of force value indicates that the force was applied in a caudal direction, and a positive angle of force value indicates that the force was applied in a cranial direction. MS represents the values for the simulated salto without any guiding hand contact force.*

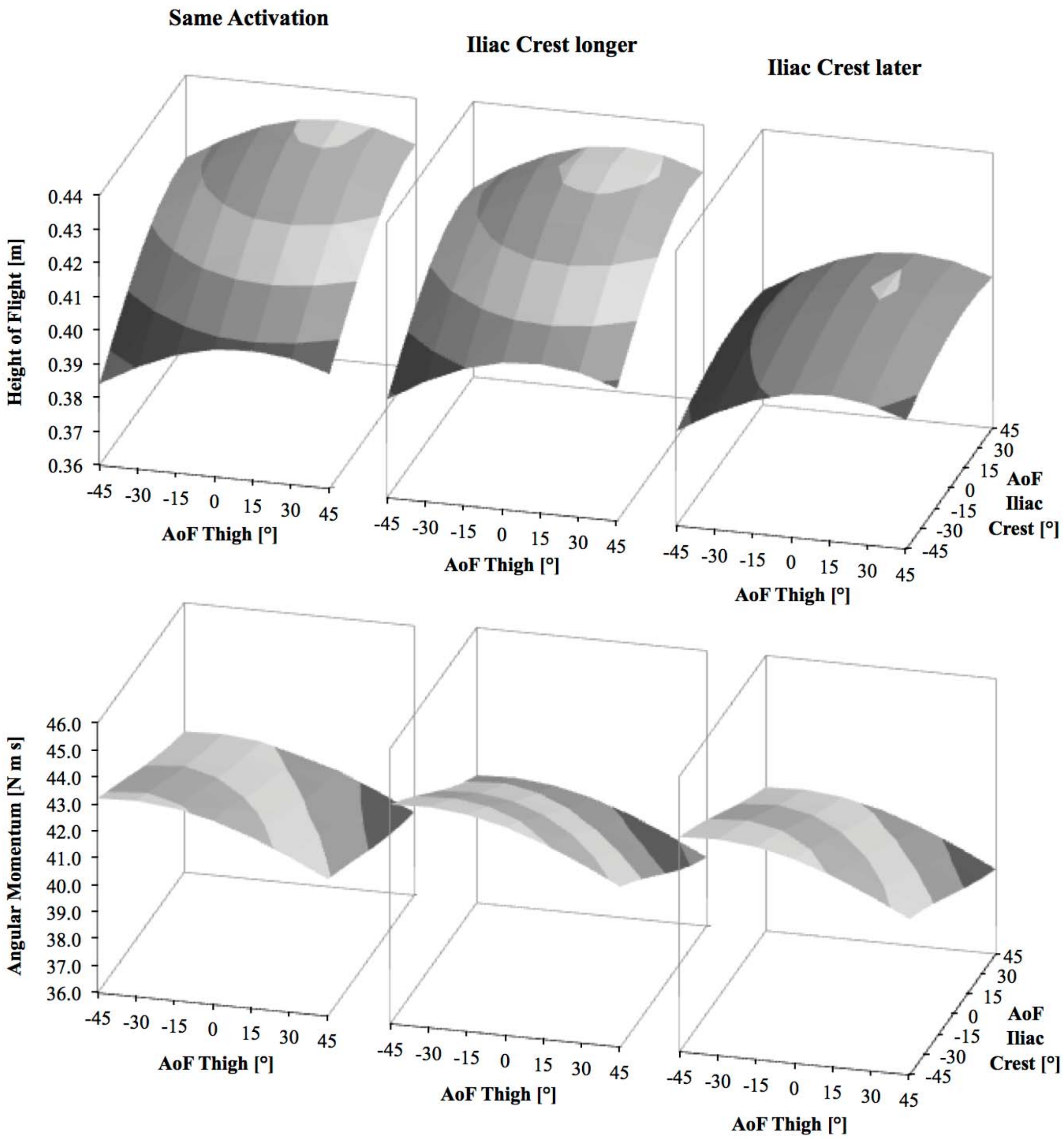

Figure 4. Combined effects (conditions 2a–c) when applying guiding hand contact forces on the thigh and iliac crest in different directions and with different timings (simultaneous on thigh and iliac crest, longer on iliac crest, later on iliac crest) on angular momentum and height of flight of the backward salto. *Note: A negative angle of force value (AoF) indicates that the force was applied in a caudal direction, and a positive angle of force value indicates that the force was applied in a cranial direction.*

DISCUSSION

The aim of the simulation was to explore the effects of manual guidance (input) on movement kinematics (output). Initially, a good match between the simulated movement and a videotaped performance is required. The low root mean square value of 1.8° and the time difference of only 0.0033 s between simulated movement and videotaped performance meant that we had achieved a good match for angle rotation and flight time (Hiley & Yeadon, 2007). Thus, the results of the simulation results can be considered applicable to real life.

We found that late hand application on the iliac crest had only a weak effect on height of flight but a similar effect on angular momentum to early or longer hand application on iliac crest. Thus, a coach might use this technique to rescue spot if a gymnast needs a bit more angular momentum and height to land on the feet (Sands, 1996). The advantage would be that in comparison to early hand application on the iliac crest, the output in angular momentum is similar, but the reaction time for the coach is greater and thus this technique should be easier to use based on motor anticipation and control (Schmidt & Lee, 2011). In other words, it is not necessary to support the gymnast with one hand on the iliac crest immediately at the takeoff point if the performance of the backward salto is made automatic; the coach could "wait" 0.10 s and still be able to produce the same output in angular momentum. But only in regard to rescuing this planned movement because spotting is rarely effective to react on unplanned failures (Sands et al., 2011).

Additionally, according to our results, the coach can adjust the amount of height of flight by defining the timing of the isolated hand support at the iliac crest. Given that the applied force direction is approximately orthogonal to the gymnast's longitudinal axis (about -15° – 0°, see Figure 3), the earlier or longer the force is activated the stronger the gymnast can be supported in the height of flight without changing the angular momentum. For that, the coach needs to guide the gymnast in an appropriate way. Meaning, it is necessary to rotate the pressure at the iliac crest with the gymnast's salto rotation and it is not sufficient just pushing the hand of the coach upwards. This could become important when the gymnast is at the end of the learning process and wants to fine-tune the performance (Magill & Anderson, 2014).

But if the gymnast needs more support and it is necessary for the coach to apply help immediately at takeoff, a combined effect on height of flight and angular momentum is possible with an isolated hand application on the thigh. Thus, the coach has to anticipate the hand application and it will always enhance both the height of flight and the angular momentum because the hand application results in an eccentric force (McGinnis, 2013).

For the combined hand applications, our results show a small effect on height of flight when application of the hand to the iliac crest was later than that to the thigh (condition 2c) compared to a simultaneous activation (condition 2a), but the two conditions produced almost the same effect on angular momentum. Later activation on the iliac crest led to lower increase in height of flight than simultaneous activation. Thus, the timing of application may determine how height and angular momentum change depending on the level of the gymnast. It seems that the timing is a better control parameter than angle or amount of force, since it is a more ballistic movement for the coach where he or she has to anticipate the forces and their directions (Schmidt & Lee, 2011).

There are some limitations of this study and one aspect should be highlighted: Possible and unpredictable interactions between coach and gymnast in the real world—such as reflexive movements or changes of the direction and amount of added force during the whole movement—were not part of the simulation model. However, it might be interesting to explore how differences in the gymnast's position and differences in the coach's hand application during the flight phase are related to differences in salto performance. This would necessitate developments of the simulation model.

CONCLUSION

The results of our simulation lead us to conclude that coaches have to decide in advance what hand application they want to use for the planned support—a securing technique with one hand at the iliac crest which still allows the gymnast to fine-tune the performance or support during the movement with one or two hands immediately at the takeoff phase.

REFERENCES

Arkaev, L., & Suchilin, N. (2004). *How to create champions*. Oxford: Meyer & Meyer Sport (UK).

Armstrong, T. R. (1970). *Feedback and perceptual-motor skill learning: A review of information feedback and manual guidance training techniques: Tech. Rep. No. 25*. University of Michigan, Department of Psychology.

Cagran, C., Huber, P., & Müller, W. (2010). Dynamic force measurements for a high bar using 3D motion capturing. *Journal of Biomechanics*, *43*(4), 767–70. doi:10.1016/j.jbiomech.2009.10.035

Chow, J. W., & Knudson, D. V. (2011). Use of deterministic models in sports and exercise biomechanics research. *Sports Biomechanics*, *10*(3), 219–233. doi:10.1080/14763141.2011.592212

Čuk, I., Atiković, A., & Tabaković, M. (2009). Tkachev salto on high bar. *Science of Gymnastics Journal*, *1*(1), 5–13.

Gervais, P., & Dunn, J. (2003). The double back salto dismount from the parallel bars. *Sports Biomechanics / International Society of Biomechanics in Sports*, *2*(1), 85–101. doi:10.1080/14763140308522810

Gu, Y., & Li, J. (2007). Dynamic Simulation of Tennis Racket and String. *International Journal of Sport Science and Engineering*, *1*(1), 55–60.

Heinen, T., Jeraj, D., Vinken, P. M., Knieps, K., Velentzas, K., & Richter, H. (2011). What it takes to do the Double Jaeger on the high bar. *Science of Gymnastics Journal*, *3*(3), 7–18.

Heinen, T., Pizzera, A., & Cottyn, J. (2009). When is manual guidance effective for the acquisition of complex skills in Gymnastics? *International Journal of Sport Psychology, 40*, 1–22.

Heinen, T., Vinken, P., & Ölsberg, P. (2010). Manual guidance in gymnastics: a case study. *Science of Gymnastics Journal*, *2*(3), 43–56.

Hiley, M. J., & Yeadon, M. R. (2007). Optimisation of backward giant circle technique on the asymmetric bars. *Journal of Applied Biomechanics*, *23*, 300–308.

Hiley, M. J., & Yeadon, M. R. (2008). Optimisation of high bar circling technique for consistent performance of a triple piked somersault dismount. *Journal of Biomechanics*, *41*(8), 1730–1735. doi:10.1016/j.jbiomech.2008.02.028

Hiley, M. J., & Yeadon, M. R. (2013). Investigating optimal technique in a noisy environment: application to the upstart on uneven bars. *Human Movement Science*, *32*(1), 181–191. doi:10.1016/j.humov.2012.11.004

Magill, R., & Anderson, D. (2014). *Motor learning and control: Concepts and applications*. Singapore: McGraw-Hill Education.

McGinnis, P. M. (2013). *Biomechanics of Sport and Exercise*. Champaign: Human Kinetics.

Mkaouer, B., Jemni, M., Amara, S., Chaabèn, H., & Tabka, Z. (2012). Kinematic and kinetic analysis of counter movement jump versus two different types of standing back somersault. *Science of Gymnastics Journal*, *4*(3), 61–71.

Sands, W. (1996). How Effective is Rescue Spotting? *Technique*, *16*(9), 3–7.

Sands, W. A., McNeal, J. R., Jemni, M., & Penitente, G. (2011). Thinking sensibly about injury prevention and safety. *Science of Gymnastics Journal*, *3*(3), 43–58.

Schmidt, R. A., & Lee, T. D. (2011). *Motor Control and Learning*. Champaign: Human Kinetics.

Shapiro, R. (1978). Direct linear transformation method for three-dimensional cinematography. *Research Quarterly*, *49*, 197–205.

Sheets, A. L., & Hubbard, M. (2008). Evaluation of a subject-specific female gymnast model and simulation of an uneven parallel bar swing. *Journal of*

Biomechanics, *41*(15), 3139–3144. doi:10.1016/j.jbiomech.2008.08.027

Sheets, A. L., & Hubbard, M. (2009). Influence of optimization constraints in uneven parallel bar dismount swing simulations. *Journal of Biomechanics*, *42*(11), 1685–1691. doi:10.1016/j.jbiomech.2009.04.014

Simi Reality Motion Systems (2012). *Simi Motion version 8.5*. Unterschleissheim, Germany.

Yeadon, M. R. (1990). The simulation of aerial movement - II. A mathematical inertia model of the human body. *Journal of Biomechanics*, *23*(1), 67–74.

Yeadon, M. R., & Morlock, M. (1989). The appropriate use of regression equations for the estimation of segmental inertia parameters. *Journal of Biomechanics*, *22*(6-7), 683–689.

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