WHAT IT TAKES TO DO THE DOUBLE JAEGER ON THE HIGH BAR?

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Abstract

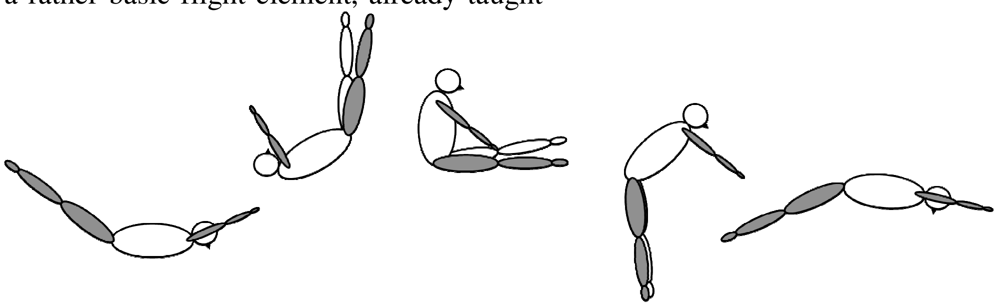
Nowadays, the Jaeger (forward salto behind the bar to regrasp) is seen as a basic flight element, already taught early in a gymnast's career. Acknowledging, that gymnasts have made advances in the development of new techniques on the high bar, the aim of the present study was to show that the double Jaeger is actually possible to be performed, and to specify the mechanical conditions one athlete must provide to have the competence to perform. A computer simulation model was used to investigate the mechanical conditions of different variants of the double Jaeger (tucked and piked). Input to the model comprised a national level gymnast's segmental inertial parameters, and the gymnast's performance in terms of the calculated and smoothed angle-time histories of Jaeger and Gaylord performances. Initial conditions consisted of the gymnast's vertical and horizontal release velocities of the center of mass, the angular velocity about the transverse axis, and the joint angles at release. Model output comprised the resulting motion of the gymnast. A systematical variation of the skill's parameter space led to a total of n = 940896 simulations. From these, 3.26% were successful for the double tucked Jaeger, and 2.50% were successful for the piked variant. Due to the simulation it can be concluded, that the double Jaeger is a hypothetically feasible skill for gymnasts who can produce a defined angular momentum together with a defined time of flight.

Keywords**:** *simulation, motor control, techniques, gymnastics.*

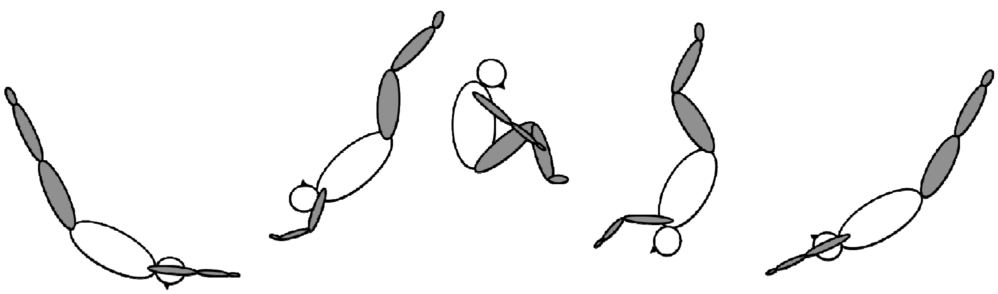
INTRODUCTION

In the last decades, Olympic gymnasts have made advances in the development of new techniques and original maneuvers on the high bar (Brüggemann, 1994; Prassas, Kwon & Sands, 2006; Čuk, Atiković & Tabaković, 2009). For instance, gymnasts have recently performed the Tkatchev Salto and the Jaeger in layout posture with double twist on the high bar. Skills on the high bar have long been subject to biomechanical analyses, and research has mainly focused on dismounts, flight elements and the mechanics of the associated giant swings (Brüggemann, Cheetham, Alp & Arampatzis, 1994; Prassas et al., 2006). Techniques of simulating and modeling aerial performance have provided insights in the underlying processes of current performances and movement techniques, which are both important for coaches and researchers (Hiley, Yeadon & Buxton, 2007; Yeadon, 1997). Furthermore, "new" techniques and elements have been demonstrated by using computer simulation (e.g, Hiley, & Yeadon, 2005; Nissinen, Preiss & Brüggemann, 1985). It was for instance recently shown, that the Tkatchev Salto is a biomechanically plausible maneuver for those gymnasts who are able to perform the straight Tkatchev with a defined time of flight (Čuk et al., 2009). From this point of view, the aim of the current study was to analyze the mechanical conditions under which a "new" element, the double Jaeger, would be possible to perform. In order to approach this aim, a computer simulation model was used.

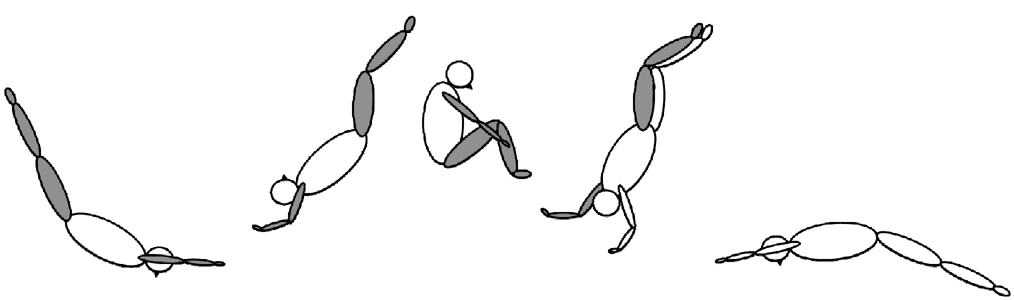
Nowadays, the single Jaeger is seen as a rather basic flight element, already taught early in a gymnast's career (Arkaev & Suchilin, 2004). In it's original execution, the gymnast releases the bar from an undergrip, performs a forward salto behind the bar in straddled posture, and regrasps the bar after finishing the salto (see Figure 1a). The Jaeger can be divided into the following four phases: (1) preparation (2) release, (3) flight and (4) regrasp. (cf., Holvoet, Lacouture & Duboy, 2002; Čuk, 1995; Fink, 1988).



(a)



(b)



(c)

Figure 1. *Picture sequences of the straddled Jaeger salto (a), the tucked Gaylord salto (b) and the tucked Pegan salto (c). Note, that the right arm and the right leg is marked in grey.*

The gymnast has to generate sufficient angular momentum during the preparation phase towards the release, and to obtain adequate height during the flight phase in order to have enough time in the air to complete the intended salto rotation. The flight curve (determined by the velocity of the center of mass at release) should guarantee a safe regrasp of the bar and the continuation of the routine (Brüggemann, Cheetham, Alp & Arampatzis, 1994). Once, the gymnast has released the bar, the movement options are constrained due to the fact, that the release velocity predetermines the flight path, and the magnitude and direction of the angular momentum with respect to the center of mass cannot be changed (Brüggemann, 1994; Raab, de Oliveira & Heinen, 2009). The gymnast can only change his or her moment of inertia during the flight phase by changing body posture in order to increase or decrease his angular velocity or to initiate or to end twists (Brüggemann, 1994).

Brüggemann et al. (1994) analyzed 70 dismounts and release-regrasp skills on the high bar during the men's high bar competition at the 1992 Barcelona Olympic games. With regard to the Jaeger, the authors found a vertical release velocity of the center of mass of 3.84 ± 0.25 m s^{-1}, and an angular momentum about the transverse axis of 31.8 ± 10.5 N m s (with respect to an "average" gymnast of 1.60 m body height and 62 kg body weight). Additionally, Gervais and Tally (1993) analyzed the performances of 15 male gymnasts during the 89 Canadian National Gymnastics Championships. The authors found that the trajectory of the center of mass in the Jaeger was near vertical ($87 \pm 4°$), resulting in a predominantly vertical velocity at release with an estimated airborne time of 0.87 ± 0.08 s. The height of the center of mass during flight was 0.83 ± 0.15 m above release. The hip angle showed negative values of $-36 \pm 8°$, and the center of mass was 0.02 ± 0.80 m relative to the bar at release. Gymnasts regrasped the bar slightly below the horizontal axis (center of mass: -0.15 ± 0.09 m).

Meanwhile another point of interest was the question of feasibility of a "new" element: the double Jaeger. According to some anecdotic evidence, the former top level gymnast Valeri Liukin already practiced the double Jaeger in tucked body posture in training more than 20 years ago, but he never performed the skill in competition (personal correspondence with Hardy Fink and Edouard Iarov). Nissinen et al. (1985) used a two-dimensional computer model to simulate human airborne movement on the horizontal bar to investigate this skill. The authors were the first to simulate a double Jaeger in tucked body posture and stated, "According to our simulation the forward double somersault tucked would be a very difficult movement to perform. The initial values had to be unrealistically modified in order to make this movement at all possible" (p. 375). Apart from the fact that the authors did not present any data to support their conclusions, one has to take into account that the analyses were conducted more than 20 years ago. Not only the gymnasts but also the equipment made significant improvement during the last decades, making more dynamic elements, like the Gaylord or Pegan, possible (Prassas et al., 2006). Moreover, computer simulation techniques have also improved, leading to more detailed and more precise simulations of complex skills (Yeadon & King, 2008). Therefore, the present study is a first attempt to investigate the mechanical conditions under which a double Jaeger would be possible to be performed.

Gymnasts are, however, able to perform release-regrasp skills with more than one salto rotation on the high bar, such as the Gaylord salto (one and a half salto over the high bar to regrasp, see Figure 1b) or the Pegan salto (Gaylord with additional half twist prior to regrasp; see Figure 1c). Čuk (1995) as well as Brüggemann et al. (1994) analyzed Gaylord and Pegan saltos on the high bar. Brüggemann et al. (1994) found, that athletes generated vertical release velocities of 4.22 ± 0.33 m s^{-1} in the Gaylord with angular momentum about the transverse axis of about 39.2 ± 6.3 N m s (with respect to an "average" gymnast of 1.60 m body height and 62 kg body weight). Čuk (1995) found the highest vertical release velocity for a Pegan (v = 5.31 m s^{-1}). The author reported a time of flight of 0.80 s for the Gaylord and 0.92 s for a Pegan salto.

From the current research it can be concluded that gymnasts are able to generate approximately 12% higher angular momentum, and a 16% higher vertical release velocity when performing a Gaylord or a Pegan salto as compared to a single Jaeger salto (cf., Brüggemann et al., 1994). From this it was hypothesized, that the aforementioned differences might account for the realization of a "new" element, the double Jaeger, in which athletes potentially need to generate larger amounts of linear momentum, angular momentum, or both until they release the bar. To test this hypothesis, the parameter-space (number and distribution of movement options) of the double Jaeger was explored by systematically varying the motion of a single Jaeger in a computer simulation model. In particular, the mechanical conditions were investigated, that would result in a regrasp after a defined salto rotation angle.

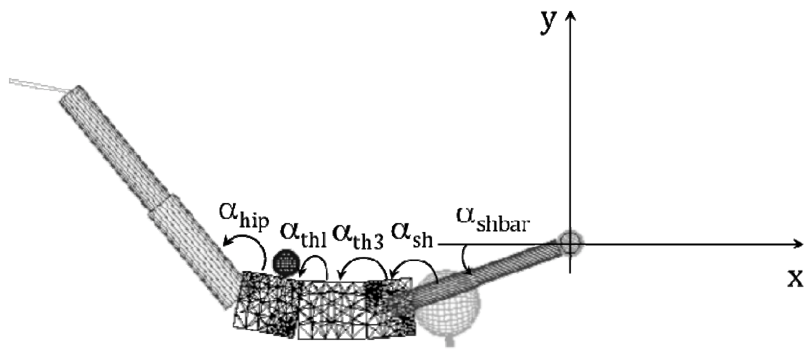
METHODS

Data collection

The data were collected in collaboration with a national level male gymnast (23 yrs, 1.67 m, 70 kg) during training while he performed single layout Jaegers (7 trials) and tucked Gaylords (7 trials) from undergrip. The performances were videotaped with two Casio Exilim Pro EX F1 cameras, operating at 300 fps (spatial resolution: 512 x 384 pixels). The two cameras were placed approximately 15 meters away from the high bar, and above the stands with an angle of 90° between the optical axes. The object field was calibrated with a 4 x 4 x 1 m calibration cube filmed before and after the performances. Two failed trials were excluded from the further analysis, because the gymnast regrasped 6 of the 7 Jaegers as well as 6 of the 7 Gaylords. Two independent national level coaches rated the 12 remaining trials with regard to their movement quality. They were asked to serialize the six performances of each skill and pick the best performance out of the six. Both coaches picked the third performance of the Jaeger and the fourth performance of the Gaylord. The gymnast's best performances were digitized using the Software WinAnalyze3D (Mikromak, 2008). The 3D coordinates of the body landmarks were reconstructed from the digitized data using the DLT technique (Shapiro, 1978). A digital filter (cut off frequency = 8 Hz) for data smoothing was applied and a mean temporal error of ± 0.0033 s, and a mean spatial error of ± 0.007 m were calculated from the data. The corresponding joint angle histories were calculated from the 3D coordinates of the segment endpoints.

Simulation Model

A computer simulation model for skills in gymnastics was built with the help of the computer software MSC.visualNastran 4D version 7.1 build 81 (copyright 1996-2003 MSC.Software). The model consisted of 16 segments representing 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 head of the gymnast. 15 joints connected the segments. The model was customized to an elite gymnast through the determination of subject-specific inertial parameters (cf., Yeadon, 1990a; Yeadon & Morlock, 1989). Input to the model comprised the segmental inertial parameters, the gymnast's performance in terms of the calculated and smoothed angle-time histories. Initial conditions consisted of the gymnast's vertical and horizontal release velocities of the center of mass, the angular velocity about the transverse axis, and the joint angles at release. The joint angles at release that were different from zero are shown in Figure 2a. These were the shoulder bar angle (α_{shbar} = -20°), the shoulder angle (α_{sh} = -15°), the angle between upper and middle trunk (α_{th3} = -5°), the angle between middle and lower trunk (α_{thl} = -10°), and the angle between the lower trunk/hips and the thighs (α_{hip} = -40°).



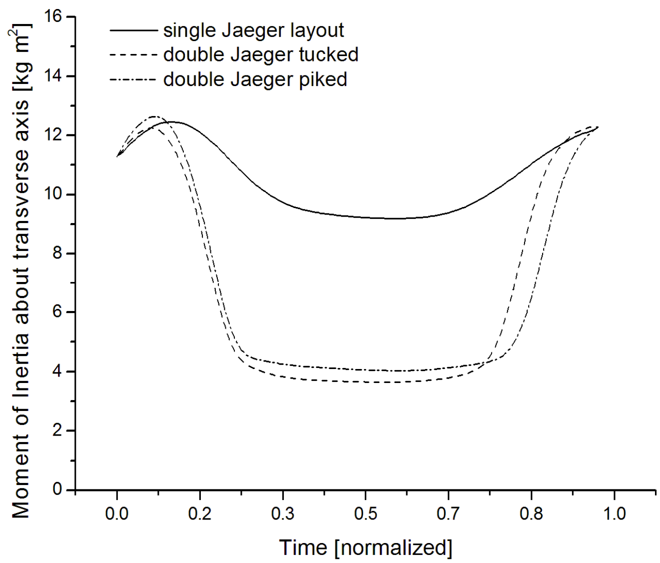


Figure 2. *(a) Graphical representation of the simulation model and definition of the global coordinate system as well as the body angles (extension/flexion) whose initial conditions were different from zero. The black circle represents the position of the model's center of mass. (b) Time-normalized course of moment of inertia about the transverse axis in different Jaeger salto simulations.*

The Kutta-Merson algorithm was used with a frame rate of 300 frames per seconds and a variable integration step size of 0.00167 seconds to solve the model's motion. Output from the model comprised the resulting motion of the gymnast. A three-dimensional computer graphics model of the human body was used to illustrate the model output after the motion was solved (see Figure 2a and Figure 3).

Procedure

The procedure in the present study consisted of two steps. In the *first step* the Jaeger in layout position was simulated based on the performances of the national level gymnast. Therefore the gymnast's angle-time histories were integrated together with the gymnast's vertical and horizontal velocity at release, as well as the angular velocity about the transverse axis at release, in the present model.

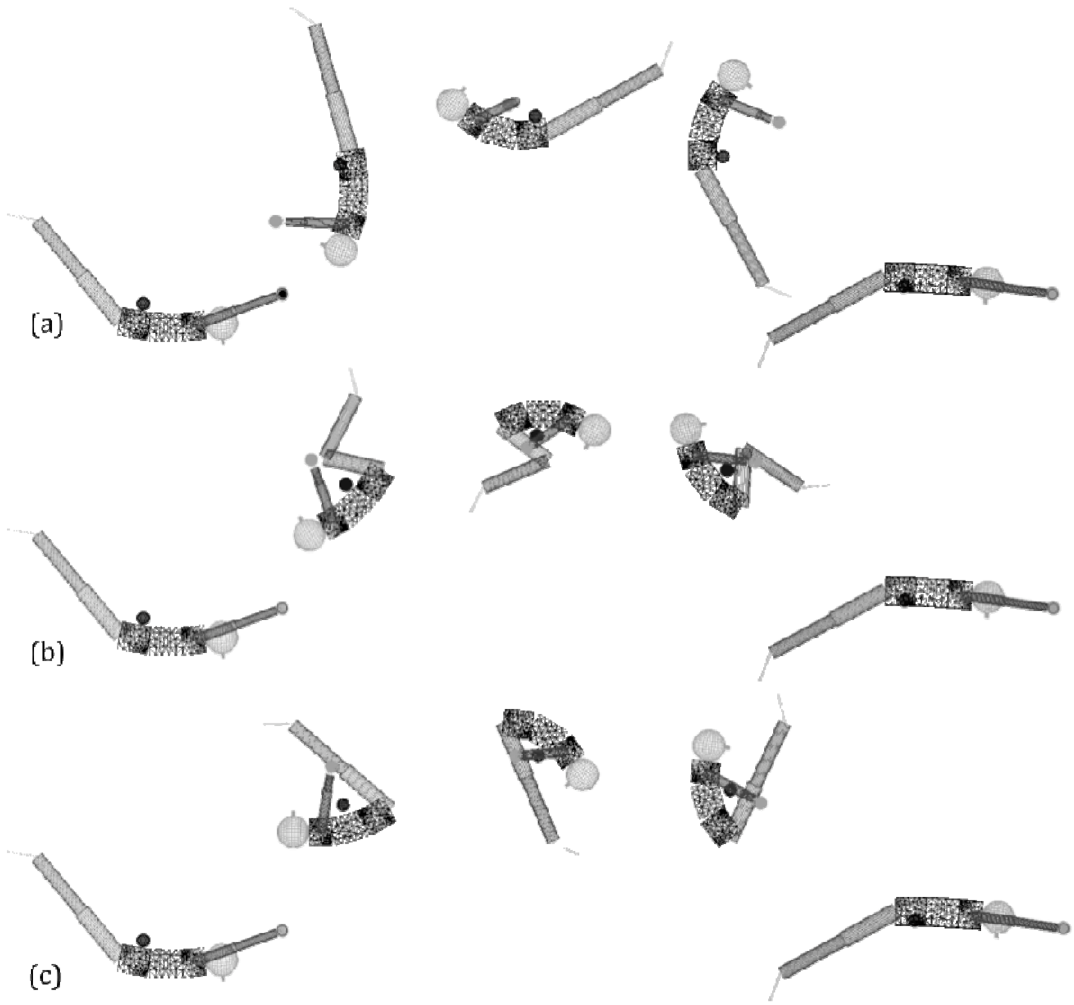


Figure 3. *Picture sequences of the optimized simulation outputs for the single Jaeger in layout posture (a), the double Jaeger in tucked posture (b), and the double Jaeger in piked body posture (c).* ***Note:*** *The single Jaeger (a) was modeled from the gymnast's performance. The simulations of the double Jaeger in tucked body position (b), and piked body position (c) used the same release angles as the original simulation, and were optimized to such an extent that the time of flight and the body configuration at regrasp matched the original simulation. The black circle represents the model's center of mass.*

In the *second step*, the amount of movement options was estimated from the resulting motion of the model for each simulated variant of the Jaeger salto. In particular, the points of interest were the number and distribution of possible movement options, resulting in a regrasp after a defined salto angle. The movement options comprised different values of angular momentum at release, and different time-courses of the moment of inertia about the transverse axis in a given time of flight. The salto angle was therefore defined by the line joining the middle of the shoulders to the middle of the knees (Brüggemann et al., 1994; Yeadon, 1990b). The salto angle was calculated for the different simulated variants of the Jaeger. The time-course of the moment of inertia was constrained to biomechanically plausible time-courses. The time-courses were derived following the results of analyses of the Gaylord performance of the expert gymnast together with results from the current literature (Brüggemann et al., 1994; Čuk, 1995). The moment of inertia about the transverse axis at release and regrasp, as well as the body orientation and joint angles were matched with the values of the simulated layout Jaeger. This was done to optimize the model's performance, assuming that a gymnast performing the Jaeger in this way would be able to continue his routine after regrasp.

Batch simulations were run, varying the angular momentum at release systematically about ± 10 N m s (cf., Brüggemann et al., 1994; Gervais & Tally, 1993), the moment of inertia about ± 0.5 kg m^2 (Knoll, 1999; Kerwin, Yeadon & Lee, 1990) and its significant events in its time-course about ± 40 ms (Latash, 2008). One simulation cycle was marked as successful if the model produced a salto rotation angle between ± 5° of the original rotation angle. The batch simulations were carried out in 10 steps for each combination of all mentioned parameters.

RESULTS

Original performance of the Jaeger

Integrating the gymnast's angle-time histories together with the gymnast's vertical and horizontal velocity at release, as well as the angular velocity about the transverse axis at release in the present model, led to a successful performance of the single Jaeger Salto in layout position (Figure 3a). The salto angle, the time of flight, and the angular momentum were calculated from the original performance of the single Jaeger salto as well as from the Jaeger performance of the simulation model. The time courses of both angles, the times of flight and the angular momentum were compared in order to evaluate the simulation model. The simulated salto rotation angle matched the recorded angle within 1.7° RMS difference (cf., Hiley & Yeadon, 2007) The time of flight matched the original performance within 0.0033 seconds, and the angular momentum about the transverse axis matched the actual performance within 0.7%.

Z-tests on the corresponding values were calculated in order to compare the model's kinematic parameters with published data of Gervais and Tally (1993) and Brüggemann et al. (1994). The time of flight for the single Jaeger salto in layout position was 0.96 seconds (z = 1.10, p = .14, cf., Gervais & Tally, 1993). The model's center of mass was 0.07 m below the bar at release (z = -0.11, p = .91, cf., Gervais & Tally, 1993). The model achieved a height of flight of 1.10 m (z = 1.80, p = .07, cf., Gervais & Tally, 1993) and regrasped the bar having it's center of mass 0.05 m above the bar (z = 2.22, p = .03, cf., Gervais & Tally, 1993). The model's angular momentum was normalized to a body weight of 62 kg and a body height of 1.60 m in order to permit comparison with the results of Brüggemann et al. (1994). Therefore, the absolute values of the angular momentum were multiplied by a normalization factor k (Knoll, 1999; Kwon, 1996). The factor k was expressed as follows:

$$k = \frac{m_0}{m} \cdot \left(\frac{h_0}{h} \right)^2$$

m_0 represents the body weight (62 kg) and h_0 represents the height (1.60 m) characterizing an "average" gymnast (see Brüggemann et al., 1994). m and h represent the body weight and height of the participating gymnast in the present study. The normalized angular momentum about the transverse axis was 53 N m s. This value was not significantly different from previously published results (z = 0.77, p = .44, cf. Brüggemann et al., 1994). The salto rotation angle was γ= 330.4°.

Simulated performance of the double Jaeger

The movement options were estimated from the resulting motion of the model for each simulated variant of the double Jaeger in tucked and piked body posture. In particular the points of interest were number and distribution of possible movement options, resulting in a regrasp after a defined salto rotation angle. Furthermore the focus lay in the maximal angular velocity about the transverse axis during the flight phase. Running batch simulations, varying the angular momentum at release, and the time course of the moment of inertia (absolute values and significant events in its time-course) led to a total of N = 940896 simulation cycles. From these, n = 30672 (3.26 %) were found to be successful for the double Jaeger salto in tucked position (see Figure 3a), and n = 23481 (2.50 %) were found to be successful for the double Jaeger salto in piked position (see Figure 3b), leading to a regrasp after rotating 690.4° ± 5°. An optimized performance of the double Jaeger in tucked body position is shown in Figure 3b, and an optimized performance of the double Jaeger in piked body position is shown in Figure 3c to illustrate the resulting simulation output. The resulting motions were optimized to such an extent that the time of flight and the body configuration at regrasp matched the original simulation. The minimum moment of inertia was reached after approximately 28 % of the movement time from release to regrasp in the tucked variant, and after approximately 26 % of the movement time in the piked variant.

An inspection of the distribution of movement options for the double Jaeger in tucked position revealed, that there existed a clear trend towards achieving a minimal critical angular momentum about the transverse axis to cover the full range of movement options in different flight durations. The number of movement options increased quadratic as a function of angular momentum about the transverse axis (R^2 = .98, Cohen's f^2 = 49.0, p < .01). The minimum value was 59 N m s, such that the model covered the full functional range of movement options. This value was not significantly different from the values, that Brüggemann et al. (1994) found for the Jaeger salto, after rescaling them to the inertial characteristics of the participating national level gymnast (z = 1.53, p = .06). The values of the maximum angular velocity about the transverse axis ranged between 786 ° s^{-1} and 1024 ° s^{-1} with a mean value of 925 ± 53 ° s^{-1}.

An inspection of the distribution of movement options for the double Jaeger in piked position revealed, that there also existed a clear trend towards achieving a minimal critical angular momentum about the transverse axis to cover the full range of movement options with respect to different flight durations. The number of movement options increased linear as a function of angular momentum about the transverse axis (r = .97, p < .01, Cohen's f^2 = 15.7). The minimal critical value was approximately 61 N m s, and assured, that the model covered the maximum functional range of movement options. This value was significantly higher than previously published values for the Jaeger salto (z = 1.69, p = .04; cf., Brüggemann et al., 1994) after controlling for body height and weight. However, there was no significant difference from published values for the Gaylord Salto (z = 1.05, p = .14). The values of the maximum angular velocity about the transverse axis ranged between 777 ° s^{-1} and 945 ° s^{-1} with a mean value of 884 ± 43 ° s^{-1}.

DICSUSION

The aim of the present study was to find out if a "new" element, the double Jaeger, would be possible to be performed in general and to analyze the mechanical conditions under which this is the case. Therefore the parameter space (number of movement options) was explored in different variations of the skill. Given, that gymnasts are able to generate approximately 12% higher angular momentum and 16% higher vertical release velocities when comparing the Jaeger with a structural similar movement such as the Gaylord or the Pegan salto, it can be hypothesized, that these "mechanical resources" might account for the realization of a "new" element, the double Jaeger.

For the present study a simulation model for gymnastic skills was used based on the performance of Jaegers and Gaylords on the high bar of one national level gymnast. Concerning the results it can be stated, that the present model represented the performance of a single Jaeger in layout posture quite adequately (e.g., RMS difference = 1.7° between recorded and simulated salto angle). The results of the subsequent analyses revealed that the double Jaeger in tucked or in piked body position can be realized with biomechanically plausible time courses of the moment of inertia about the transverse axis (derived from the analysis of a Gaylord salto) together with different combinations of angular momentum about the transverse axis and time of flight.

From the data it can be concluded, that the double Jaeger is possible in either tucked or piked body posture, because both skills could be realized in the full range of available movement options, assuring, that at least the gymnast could achieve a minimal critical value of angular momentum. When performing the tucked variant, a gymnast weighting 70 kg with a body height of 1.67 m should be able to generate an angular momentum of at least 59 N m s with a minimal time of flight of 930 ms, to cover the full range of movement options. For the piked variant, the same gymnast should be able to produce an angular momentum of at least 61 N m s with a minimal time of flight of 930 ms. In both variants, the minimum moment of inertia should be reached after approximately 26 - 28 % of the movement time from release to regrasp. Quite surprisingly, the minimal critical value was not significantly different from previously published values of either the Jaeger or the Gaylord salto (cf., Brüggemann et al., 1994; Nissinen et al., 1985) and therefore it can be concluded that – at least from a biomechanical point of view – the double Jaeger should be realizable by well-trained gymnasts.

In addition, it was found, that the highest angular velocities about the transverse axis occurred in the tucked variant of the double Jaeger (v_{max} = 1024 ° s^{-1}). Analyses of the performance of world's best athletes reveals, that they realize angular velocities about the transverse axis up to 1300 ° s^{-1} (Krug, 1997) with similar or even smaller moments of inertia about the transverse axis that was found for the simulation of the double Jaeger. From this it can be concluded, that trained athletes should be able to deal with angular velocities larger than 930 ° s^{-1} when performing the double Jaeger in either tucked or piked body position (von Laßberg, Mühlbauer & Krug, 2003; Krug, 1997).

Despite its feasibility, there may be three arguments why the Jaeger Salto on the high bar is not performed that often in international competitions, and potentially, why the double Jaeger may not be attractive for gymnasts to learn as compared to other release-regrasp skills. First, the Jaeger salto is a forward salto during which the athlete "sees" the high bar relatively late prior to regrasp, and therefore has less time to adjust the regrasp based on visual information, as compared to other flight elements, like the Tkatschev (Gervais & Tally, 1993; Raab, de Oliveira & Heinen, 2009). Second, the athlete has to reverse the direction of his rotation when regrasping the bar, as compared to other flight elements, like the Kovacs Salto if he intends to perform a subsequent giant swing. This significantly constrains the movement options after regrasping the bar in terms of subsequent flight elements and in terms of the energy exchange between the gymnast and the high bar (Brüggemann et al., 1994). Furthermore, it may be not attractive for gymnasts to perform the Jaeger due to the current competition rules of the International Gymnastics Federation (FIG, 2009). In particular, the flight elements on high bar depend on precise execution, and irregularities in movement execution could lead to a fall off the apparatus, and/or to score deduction if the movement cannot be performed according to the officiating guidelines. That is why elite gymnasts may prefer a gymnastic routine, which is based on a low risk decision. Another aspect refers to the question how to integrate the double Jaeger into a gymnastic routine, so that there is enough energy to perform the skill on the one hand, and to make it possible for the gymnast to perform his following gymnastic routine without score deduction on the other hand.

Acknowledging that there are several limitations of the present study two specific aspects are discussed in the following: First, a simulation model was used to estimate the mechanical conditions and functional range of movement options of the double Jaeger, but it was not evaluated if a real gymnast would be able to perform the double Jaeger on the high bar. Moreover officially it is not known that someone has tried to perform the double Jaeger so far in competition. Acknowledging, that gymnastic equipment as well as methodical progressions made significant enhancements in the last decades, it is likely, that nowadays practitioners may find strategies to develop methodical progression for the skill, and gymnasts will be able to realize the skill.

Second, the simulation model consisted of 16 segments (rigid bodies), and 15 joints. It was customized to an elite gymnast through the determination of subject-specific inertial parameters. The model did not comprise parameters related to the muscles, such as force-length or force-velocity relationships. Furthermore, the preparatory phase of the Jaeger was not part of the simulation model. However, one might be interested in how the actions of different muscles may account for different Jaeger performances and/or how differences in the preparatory phase may be related to differences in Jaeger performance. This would in turn lead to necessary developments of the simulation model, which could be part of subsequent studies.

Finally, It must be stated, that progressions or training programs with the ultimate aim of enabling athletes to perform the double Jaeger, should only be developed whilst ensuring the safety of the gymnast. Computer simulation techniques may help the coach to estimate if one specific gymnast would potentially be able to perform the double Jaeger, given that the athlete provides certain prerequisites such as mastering the Gaylord and the single Jaeger with a defined linear and angular momentum. Subsequent studies should first and foremost discuss the safety conditions and coaching approaches to close the gap between the findings of a prospectively feasible skill (competence dimension) and the question of transfer to real performance of the double Jaeger.

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