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Kinematic differences between indoor and outdoor tug of war: A single case study.

Diferencias cinemáticas en el Tug of War indoor y outdoor: Estudio de caso.

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Abstract

The tug of war (TOW) is a sport with a high physical and technical demand. Very few investigations have been carried out on the biomechanics of TOW and all of them in the indoor modality. The main objective of this study is to describe and differentiate the kinematics of indoor and outdoor TOW. An experienced puller was recorded in two world championships of the two modalities in consecutive years. Although the position of the hands on the rope, the arms and the inclination of the body are similar, important differences were registered both in the lower body and in the position of the body, with both shoulders and hips forward in the case of the indoor modality and with the hip and left shoulder forward in the outdoor modality. This research evidences the different techniques used in the two modalities of TOW and their possible relationship both with the risk of injury to some parts of the body, and with the greater demands of these parts.

Keywords: tug of war; kinematic; pulling; technique

Resumen

El tug of war (TOW) es un deporte con una alta exigencia física y técnica. Se han realizado muy pocas investigaciones sobre la biomecánica del TOW y todas ellas en la modalidad indoor. El objetivo principal de este estudio es describir y diferenciar la cinemática del TOW indoor y outdoor. Se registró a un tirador experimentado en dos campeonatos mundiales de las dos modalidades en años consecutivos. Aunque la posición de las manos en la cuerda, los brazos y la inclinación del cuerpo son similares, se registraron diferencias importantes tanto en la parte inferior del cuerpo como en la posición del cuerpo, con los hombros y la cadera adelantados en el caso de la modalidad indoor y con la cadera y el hombro izquierdo adelantados en la modalidad outdoor. Esta investigación evidencia las diferentes técnicas utilizadas en las dos modalidades de TOW y su posible relación tanto con el riesgo de lesión de algunas partes del cuerpo, como con una mayor exigencia de estas partes.

Palabras clave: tug of war; cinemática; tirada; técnica

Introduction

Tug of War (TOW) is an international played sport, which consists in two teams of 8 pullers each, positioned in front of each other on a rope and the team that pulls the opposing team towards a centre line for a distance of 4 m in two pulls out of three is considered the winning team (Twif, 2021). In International TOW competitions (Outdoor and Indoor) categories are recognized (Twif, 2021). While the indoor category takes place on a rubber surface, the outdoor category takes place on land, which will be more or less soft depending on the weather conditions. In the outdoor category the pullers use boots adapted to the rules of their modality and for the outdoor category they use rubber-soled shoes. Although it is a sport with a long history and practiced all over the World, (being of the oldest), little research has been published about performance parameters (Cayero et al., 2022).

Among them, in particular, sport biomechanics represents the science that provides quantitative (and sometimes qualitative) assessments of sport performance; concretely, the kinematics and kinetics of sport movements (Zatsiorsky & Fortney, 1993). Measuring and characterizing human movements during sporting activities are nowadays a crucial aspect for coaching programs in order to assess athletes' performance, to improve technique, and thereby prevent injuries (Kos & Umek, 2018; Taborri, Palermo, & Rossi, 2019).

As far as biomechanical studies in the TOW are concerned, the biomechanics of the puller is directly related to the possible injuries he or she may suffer during the activity. In that way, some investigations describe the kinetic and kinematic characteristics of pullers (Tanaka, Ushizu, & Minamitani, 2005). In relation to the indoor kinetic aspects, these same researchers claim that the elite TOW athletes can produce force approximately 150% of the body mass in a dynamic condition and approximately 200% of the weight in a static pulling (Tanaka, Ushizu, & Minamitani, 2005). In addition, the team pulling force is about 20% smaller than sum of force exerted by 8 pullers: with the loss of force due to a lack of coordination among players (Liou, Wong, Wang, & Shin, 2005). Finally, in terms of muscle activation, although there are no studies that analyze the muscle activation of the lower body musculature in pullers, it is known that the dorsals have a high degree of activation during the pull in indoor TOW (Godfrey, Nakagawa, & Yamamoto, 2007).

Continuing to de indoor kinematic, Tanaka (Tanaka, Ushizu, & Minamitani, 2005) reported that the ideal posture in TOW was limited to the ones of body inclination of 35-40 degrees. On the relationship between body inclination and pulling force, Yamamoto et al. (Kawahara, Hosaka, Cao, & Yamamoto, 2001) reported that pulling force was increased by 1.4 kg as the degree of body inclination increased by 1 degree. In order to obtain as much pulling force as possible, angle of ankle, knee, and waist must be simultaneous and the more inclined the body is, the more traction capacity has (Kawahara, Hosaka, Cao, & Yamamoto, 2001). Ryuji et al. (Ryuji, Nakagawa, & Yamamoto, 2007) compared the positions of indoor elite pullers with those of lower level and Elite TOW indoor pullers produced the motion to pull by not only arm but also body. To hold arm to body, elite TOW indoor athletes closed their side, extended their trunk, inclined their body and lower body heavily, and also inclined their upper body slightly in comparison with average team. Pulling by throughout the body, that enable to pull a tug with all one's might. Also, Tanaka and colleagues (Tanaka, Ushizu, & Minamitani, 2005) explains something as characteristic of the kinematics of indoor TOW as the order of lower leg movement, which is rotating an ankle joint at toe off and places the toe outside. It helps sustaining the place of the leg land on against the load during swing phase of the other leg.

All the literature related to the biomechanics of TOW is focused on indoor TOW, probably because of its greater standardization and greater control over the surface variable. In contrast, studies related to injuries in this modality for example, are mostly studies or records made in outdoor TOW (Chotai & Abdelgawad, 2014; Smith & Krabak, 2002; van Heerden & van Rensburg, 2003), which greatly hinders the relationship between these two aspects. Therefore, in order to know the basis of kinematics of indoor and outdoor TOW, and their differences, the main aim of this case study is to describe and differentiate the kinematics of these two sports modalities of the same sport in one single TOW puller. We hypothesize that there will be no major kinematic differences in terms of arm technique, but that there will be major differences in the body and especially in the legs.

Materials and Methods

Participant

The participant was a Caucasian male aged 29 at the beginning of the period of study (2019) and aged 30 at the end (2020) (Height: 189 cm; Body mass: 77 kg; Body fat 7 %). He is a puller with more than 15 years of international experience and meets the characteristics of a competent TOW puller (Zhang, 2012). This participant has 8 outdoor World Championships, 7 indoor World Championships, 1 European outdoor Championship and more than 12 podiums in World Championships during his personal sports career. He was fully informed about the experiments and provided written informed consent to participate in this study. Must be noted that the obtained data were treated with the greatest confidentiality and scientific rigor, their use restricted by the guidelines for research projects following the scientific method required in each case, complying with the Organic Law 15/1999 of the 13th of December on the Protection of Personal Data (OLPPD); the proceedings used respected the ethic criteria of the Responsible Committee of Human Experimentation (established by law 14/2007, published in the Spanish Official State Gazette, n° 159) and the Helsinki Statement of 2008 (Puri, Suresh, Gogtay, & Thatte, 2009), updated in Fortaleza, October 2013 (World medical association declaration of helsinki: Ethical principles for medical research involving human subjects.2013). The study was approved by the University of Deusto Ethics Committee (M10_2017_108).

Experimental procedure

The participant was recorded in the 2019 European Outdoor TOW Championship and the 2020 World Indoor TOW Championship in which he participated.

All recordings were made during the second and third runs of the competition, and during the first minute of the duration of the runs, to ensure that the subject under analysis was sufficiently adapted to the activity and the terrain, but not fatigued. The position of the subject analyzed on the rope was first in the indoor category and third in the outdoor category.

In order to obtain more reproducible and comparable images, 10 frames of static or "hold" positions, in which the puller is exerting pressure on the rope (Tanaka et al., 2006).

Instruments

Video camera: A high-speed video camera (Exilim EX-F®1, Casio, Tokyo, Japan, resolution 512x384 pixels at 300 frames per second (fps) and shutter-speed at 1/2000 second) was mounted on a tripod to ensure a standardized height of the camera lens. For the location of the cameras, the recommendations of Puig-Diví and colleagues (Puig-Diví et al., 2019) were considered. The cameras were placed 3.5m to the puller with the optical axis perpendicular to the plane of movement and covering the field of the puller on the rope in the sagittal plane (Figure 1).

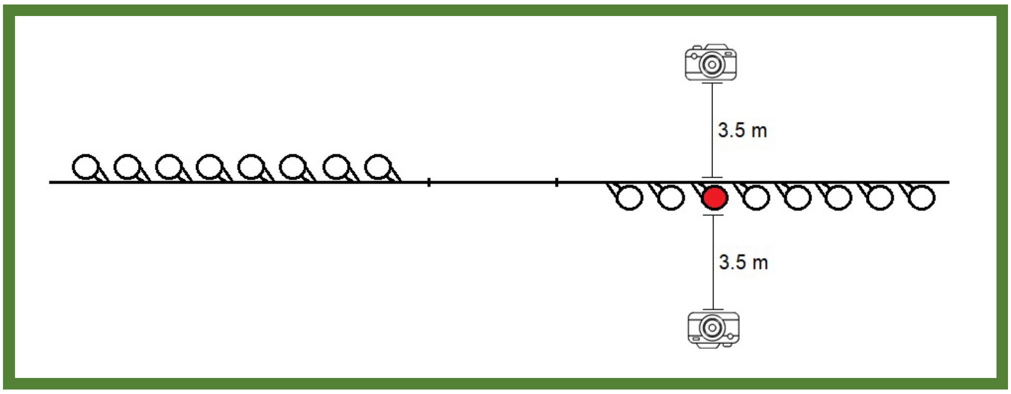
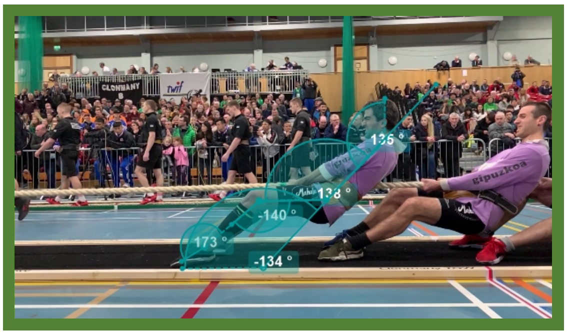
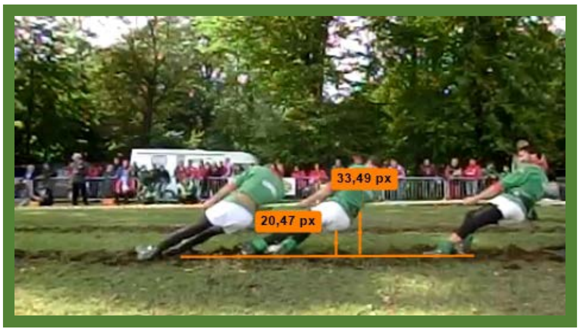


Figure 1. Position of the cameras.

Kinovea: Hip height variations, neck, shoulder, elbow, trunk, hip, knee and ankle joints kinematics in both sagittal planes during the pull were analysed using freeware motion-analysis software 2D Kinovea® (version 0.8.15, available for download at: http://www.kinovea.org) (Hong & Moon, 2018) on both sides. This tool is valid and presents reliability and was used in other sport activities in previous investigations (Balsalobre-Fernández, Tejero-González, del Campo-Vecino, & Bavaresco, 2014; Damsted, Nielsen, & Larsen, 2015; Grigg, Haakonssen, Rathbone, Orr, & Keogh, 2017) (Figure 2 a-b).



(a) Indoor.



(b) Outdoor.

Figure 2. Analysis of the pullers on two different surfaces performed with Kinovea.

Angles: The angle of flexion of the neck was measured with the intersection of two imaginary lines, one formed by the acromion in the shoulder and the anterior part of the ear (the swallow), and the other formed by the acromion and the trochanter of the femur. The inclination of the trunk, on the other hand, was obtained with the intersection between the lines formed with the one parallel to the ground and the one created between the acromion and the trochanter of the femur. Shoulder flexion was measured considering the line formed with the acromion and the lateral epicondyle of the humerus, and the line formed between the acromion and the femoral trochanter. Elbow measurements were made considering the acromion, the lateral epicondyle of the humerus and the ulnar styloid process. The degree of hip flexion was measured by reference to the acromion, femoral trochanter and femoral condylar. Knee flexion and extension were measured taking as reference points the imaginary straight lines, the trochanter and condyle of the external femur and another imaginary line of the condyle of the external femur and the external malleolus. Finally, the ankle measurements were measured using the femoral condyle, the external malleolus and the fifth metatarsal reference point as a reference.

Results

The values registered in TOW outdoor as indoor are reflected in Table 1. Although there is a clear difference between the two positions, there are certain characteristics, such as the inclination of the trunk, arms and the grip of the hands, which are similar in both modalities.

The degrees of flexion registered in the neck in the outdoor mode are about 8% lower than in the indoor mode, which has a direct relationship with the inclination of the trunk, which is 4% lower in indoor than in outdoor. The variations registered in the height of the hip due to the small steps and movements made during the pull, are practically the same in both modalities. While in the indoor they pull with the body facing forward, in outdoor they rotate the trunk to the right to accompany the rotation of the pelvis to that same side and to be able to place the feet facing the right side with the aim of increasing the surface with which they can dive into the mud.

As for the upper body, both shoulders and elbows on both sides of the body have similar angles. The variations are minimal (close to 5%) compared to those of the lower body, for example.

In the lower body, there are greater differences between modalities. The articular ranges registered in outdoor are greater, with maximum oscillations of 57º in the right knee for example. The joint ranges of the lower body in indoor remain much more uniform than those in the outdoor. The most important variation within all the joints of the lower train in indoor is 18º (left knee), while the angles registered in the outdoor, the lowest angular variation is almost equal to that value (17º in the left hip).

Without a doubt, with regard to the joints, the greatest difference is in the ankles. In outdoor, due to the boots that are used to dive into the ground, the ankles are kept in a neutral position of 90º, and with the mobility practically annulled. In the case of indoor, the ankles, besides being free, are also in an important external rotation (from the hip) and pronation or eversion.

Table 1. Angles recorded in the outdoor and indoor analysis.

	OUTDOOR		*INDOOR*		*DIFFERENCES*	
	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT
Neck	123º/126º		135º/140º		8º/14º	
Trunk inclination	132º/140º		130º/134º		-2º/-6º	
Shoulder	4º/6º	14º/19º	3º/7º	24º/26º	-1º/1º	10º/7º
Elbow	139º/140º	170º/172º	146º/148º	165º/170º	7º/8º	-5º/-2º
Hip	127º/180º	160º/177º	139º/151º	138º/146º	12º/-29º	-22º/-30º
Knee	117º/174º	136º/179º	143º/156º	140º/158º	26º- 39º	4º/20º
Ankle	90º	90º	161º/169º	165º/171º	71º/79º	75º/81º
Maximum hip height variations	35%		36,7%		1,7%	

Discussion

The main aim of this case study was to describe and differentiate the kinematics of these two sports modalities of the same sport and the results showed how there are important kinematic differences between the two positions in outdoor and indoor TOW. Although the inclination of the body and the way of grabbing the rope are quite similar in the two modalities, the position of the body, rotated in outdoor and front in indoor, and the way of performing the steps, are very different between them.

As far as the upper body is concerned, the two modalities are very similar. Depending on the technique used, pullers can keep the upper body very static and do most of the dynamic strength with the lower body (Tu, Lee, & Chiu, 2005), or not be so dynamic with the legs and take advantage of the strength of the posterior chain of the body to flex the trunk and then perform great strength in the extension of the trunk. The analyzed puller's teams, tend to be teams that try to rely more on leg strength. In order to transmit all this force to the rope, our subject uses the least efficient way of the two studied by Tang, W.-T (Tang, Liao, & Lee, 2018), which consists of placing the left hand farther to the body than the right hand on the rope.

Although the inclination of the body with respect to the horizontal of the body depends on many variables such as: the technique used by the team, the height of the pullers, also influences the level of the same, finding a greater inclination in pullers with higher level (Nakagawa, Toryu, Tanaka, Kawahara, & Yamamoto, 2005; Ryuji, Nakagawa, & Yamamoto, 2007). In addition, there is a relationship between the inclination of the body and the traction force that is performed, this being greater the greater inclination is (Kawahara, Hosaka, Cao, & Yamamoto, 2001).

It is important to take into account that in order to improve the grip on the ground and the traction that the pullers make, in the outdoor modality, all perform a rotation of the lower part of the trunk towards the right side. This rotation allows them to place their feet sideways on the ground, and to be able to pull with a greater surface area on the mud (Cayero et al., 2022).

Regarding the differences registered in the lower body, many of them are conditioned to a large extent by the material used. While in indoor TOW the pullers wear normal shoes, in outdoor TOW, they pull with boots similar to skating but without wheels, which greatly blocks the mobility of the ankle, fixing it at approximately 90º.

The greatest differences found in the kinematics of the lower body in the outdoor TOW, are probably due to the fact that in this modality, as it is a softer surface, "steps" are usually created which the pullers use to exert force on them. While in outdoor TOW the pullers have to move from one step to another taking a "step", in the indoor TOW the pullers move taking much smaller and more uniform steps (Nakagawa, Hagio, Tanaka, & Yamamoto, 2016).

Due to the biomechanical demands and the great forces applied to the rope by the pullers (Tanaka, Ushizu, & Minamitani, 2005), some injuries derived from the practice of TOW have been described. More than half of all injuries consisted involving: the back (42%), shoulder and upper extremities (23%), and knee (17%) (Smith & Krabak, 2002). The data recorded by these authors is probably due to the fact that they collected the data at the World TOW Championships held in Rochester, MN, USA in 1998, and it is an outdoor competition. Considering the data obtained in our study as far as the ankle is concerned, one of the joints that has to suffer the most in indoor TOW is the ankle, while in outdoor, it is could be the one that suffers the least inside a boot.

This research presents some limitations. On the one hand, today there are measurement systems for high-precision kinematic studies (3D video analysis through optoelectronic systems), however, the 3D optoelectronic-based methodologies still have several limitations for widespread use in sport, such as difficulties in analyzing human movement in outdoor environments, the time spent and the skills needed for the participant's sensorization and the limited calibration volume in which the analyses can be performed (de Magalhaes, Vannozzi, Gatta, & Fantozzi, 2015). This is the main reason why the aim of interfering as little as possible with the puller's activity (Calvo, Álvarez-Caldas, San Román, & Gutiérrez-Moizant, 2020) that video recording and subsequent analysis with Kinovea have been used.

Another limitation may have been that only the analysis of a single participant (case study) is carried out, making it difficult to extrapolate these data to other participant or to other positions in the rope. For example, the puller placed last on the rope (anchor) is similar to the goalkeeper in team sports, in that he has different kinematics and demands than the rest (Ibrahim, Kingma, de Boode, Faber, & van Dieën, 2019). Although the subject under analysis has been studied in two similar positions, it must be taken into account that the analysis has been performed by obtaining images in different positions, which may have influenced the results obtained.

It must be considered that in the case of TOW outdoor, the state of the ground can modify the kinematics of the pullers. Despite this, many of the characteristics described in the article (rotation of the trunk to the right, use of boots and its consequences...) will be maintained on any surface.

Finally, it is difficult to interpret or deepen on the results obtained since the previous little existing literature so far has not studied the biomechanics of outdoor TOW and very little the indoor. Studies such as this one is essential to lay the foundations and to be able to initiate more and better studies on the participants.

Conclusions

In this comparative study of the kinematics of indoor and outdoor TOW, the great technical differences between these two modalities are evident, especially in the lower body joints (hip, knee and ankle). These kinematic differences make different physical demands on joints and structures, which will be reflected in the incidence and type of injuries recorded in each of the modalities. Likewise, these differences demonstrate the importance of the need for different training approaches.

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