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FACULTEIT BEWEGINGS- EN REVALIDATIEWETENSCHAPPEN

The Biomechanical Fingerprint of a Dressage Rider

Door Amber Heidbuchel

Masterproef aangeboden tot het behalen van de graad van Master of Science in de revalidatiewetenschappen en kinesitherapie

o.l.v.
prof. dr. I. Jonkers, promotor
dr. S. Van Rossom, copromotor
P. Minguet, copromotor

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Woord vooraf

Om te beginnen zou ik graag mijn oprechte dank willen betuigen aan mijn promotor, prof. dr. Ilse Jonkers, om mij de kans te geven om mijn eigen onderzoek en masterproef op te stellen omtrent een compleet nieuw topic. Toen ik op de masterproefmarkt met een klein hartje naar haar toeging met mijn idee om de biomechanica van de ruiter te onderzoeken, bood ze mij de opportuniteit aan om mijn voorstel verder uit te werken.

Een bijzonder woord van dank wil ik richten naar mijn copromotoren, dr. Sam Van Rossom en Philippe Minguet, voor alle hulp, steun en tijd om het onderzoek mee op poten te zetten.

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Tenslotte wil ik mijn familie bedanken om altijd klaar te staan met goede raad.

Lubbeek, 4 mei 2021 A.H.

Situering

De masterproef valt binnen de onderzoeksgroep Biomechanica van de Menselijke Beweging die deel uitmaakt van het departement Bewegingswetenschappen van de faculteit Bewegings -en Revalidatiewetenschappen aan de Katholieke Universiteit Leuven. Deze onderzoeksgroep heeft als doel om bij te dragen aan een gepersonaliseerde benadering bij opbouw van trainingsschema’s of revalidatie van patiënten en atleten. Dit wordt gedaan op basis van identificatie van bewegingsgerelateerde biomarkers waarbij de mechanica en belasting van het muskuloskeletale systeem en de cellullaire respons van het individu worden bestudeerd met gespecialiseerde computertechnologie.

Deze studie onderzoekt de biomechanica van de dressuurruiter op basis van druk -en krachtmetingen op een Racewood® Eventing Simulator gecombineerd met video-analyses. De simulator is specifiek ontwikkeld voor ruiters en biedt de mogelijkheid aan om in een gecontroleerde omgeving nauwkeurige metingen uit te voeren van de positie en de inwerking van de ruiter op het paard. Tot op heden is het onderzoek van de biomechanica van de ruiter op het paard nog schaars. Dit is waarschijnlijk deels te wijten aan het feit dat onderzoek in het veld, op een echt paard, moeilijk uit te voeren is. Daarom wordt in deze masterproef verder bestudeerd welk bewegingspatroon dressuurruiters hanteren op een simulator en wat de verschillen zijn tussen verschillende competitieniveau’s.

Wanneer er bepaald is welk bewegingspatroon eigen is aan competitieve dressuurruiters, is een volgende vraag die we ons kunnen stellen welke fysieke capaciteiten de competitieve dressuurruiter nodig heeft. Als er in de paardensport gesproken wordt over conditietraining, krachtopbouw en stretching wordt er bijna altijd verwezen naar het paard. De laatste jaren krijgt de fitheid van de ruiter meer en meer aandacht, maar ook in dit topic is onderzoek nog beperkt. Daarom onderzoekt deze studie als tweede aspect de fysieke capaciteiten van dressuurruiters door middel van een reeks kinesitherapeutische testen die onder andere kracht, lenigheid, coördinatie en flexibiliteit evalueren.

Indien we een beter beeld hebben van deze twee aspecten in de paardensport kunnen we ruiters gerichter analyseren, corrigeren en op langere termijn behoeden voor blessures.

Abstract

In dressage riding, rider posture has an important role on the performance of the exercises. The purpose of this study was to evaluate rider posture on a simulator and the physical capacities as a function of rider skill level. Participants (ten experienced and twelve novice competitive dressage riders) performed an equestrian simulator test and a physiotherapeutic screening test. The experienced rider group had less variability in both left (p = 0.002) and right (p = 0.021) rein force during medium canter on the simulator. Furthermore, they showed less variability in the trunk angle (p = 0.034) and had a smaller range of motion (ROM) in the trunk during collected canter (p = 0.012) and in the knee during collected walk (p = 0.033). The shoulder angle of the experienced riders was larger in all gaits (p < .05), except during extended walk. In the physiotherapeutic screening, better results were obtained by the experienced riders in both the Star Excursion Balance Test (SEBT) with the right leg and in the Upper-Quarter Star Excursion Balance Test (UQSEBT) with the left arm in different directions (p < .05). These findings indicate that the ability to maintain a constant force on the reins and a dynamically stable posture to guide the horse towards more “collection” during riding are important indicators for good rider performance. Additionally, this study suggests that the SEBT and the UQSEBT are useful tools to screen and follow up athletic ability as a substitute to ridden trainings for equestrians.

Introduction

During dressage, an Olympic horse riding discipline, the horse and rider perform a series of predetermined exercises of varying difficulty. Dressage is often described as "horse ballet" since the horse and rider appear to dance together [1]. At competition, every exercise is scored by a judge. The horse-rider combination that performs the exercises technically best and shows the best partnership gets the highest scores.

A good riding performance is based upon a fluent horse-rider interaction, meaning that the rider's pelvis, trunk, head, and limbs should be capable of following the horse's motion passively. This leads to the formation of a dynamically stable seat which is independent of the usage of the reins or excessive squeezing of the legs to remain balanced. This way the rider can guide the horse with specific physical signals of single body parts, also referred to as "aids", without interrupting the horse's motion. When this is achieved, the rider's kinematics are more closely matched to those of the horse and are less variable [2]. The ideal dressage seat to accomplish this is described as a balanced, elastic, and upright rider's posture. In the sagittal plane, one should be able to draw a vertical line through the rider's ear, shoulder, hip, and ankle. In the frontal plane, the rider should be positioned centrally on the horse's back [3]. Studies have shown that advanced riders position their upper body closer to the vertical, more upright and have less range of motion (ROM) in the trunk, elbows and knees compared to novice riders [3, 4]. A symmetric position of the rider on the horse is considered important regarding performance and injury prevention of horse and rider. Asymmetrical positioning and guidance can interfere with the aids from the rider to perform exercises, leading to miscommunication. Subsequently, this can have a negative effect on performance and welfare of the horse and rider [5-9].

Up till now there is little description or consensus on which physical factors determine the optimal position of riders and predispose riders to better performance [1]. Rider symmetry and flexibility have received the most attention in research since these factors are seen as the most important for rider performance. Flexibility in the trunk, hips and pelvis is considered as a precondition for a supple seat [7, 9].However, other important physical factors such as balance, reaction time, muscle strength, and endurance are often neglected [1, 10]. Nevertheless, some studies suggested that endurance, reaction time, postural control and muscle strength are positively associated with rider performance [1, 10]. Conversely, although rider asymmetry is generally recognized as a negative trait, a study found that higher level dressage riders had more left-right differences in lateral bending ROM and shoulder height. This indicates that high level dressage riding induces rider asymmetry rather than improving symmetry, and may therefore reduce performance [7]. Studies have demonstrated that manual physiotherapy intervention to the lower torso [11] and pelvic region [5] focusing on motor control, mobility and soft tissue techniques can reduce rider asymmetry and improve balance. This suggests that detecting the rider's physical shortcomings by means of a physiotherapeutic screening may be important to guide interventions to improve rider performance. Better understanding the physical capacities determining rider performance can lead to corrective action to improve rider symmetry and ultimately prevent injury.

Although the effect of asymmetry in athletic performance has received widespread attention in other human-only sports, it has only received scant attention in equestrianism. This is most likely due to the difficulties of measuring horse and rider in a controlled environment [5]. There is a need to objectivate whether symmetry in the horse-rider system predisposes riders to better performance and to this aim a controlled simulator can be used. Indeed, simulator-based training is already used in a wide variety of fields. It is well-known for training airline pilots and gets increasing applications in training human and veterinary medicine students. Recently, a new generation of simulators has been developed specifically for equestrian training [12]. The simulator provides an objective measurement of the rider's position in the saddle and of the aids through which the rider controls the horse. The measurements are based upon four pressure sensors in the saddle and a force sensor in each rein. The simulator can be programmed for specific disciplines like dressage, show jumping or eventing and responds to the aids given by the rider [13]. Schooling the rider's seat, position, movements and accuracy of the aids using a simulator has already been shown to improve rider performance based on changes of joint angles of the elbow, shoulder, hip, knee and ankle towards a more upright position [14]. Horse simulator training has also been shown to be of benefit beyond equestrianism, more specific to improve postural control in patients with cerebral palsy (CP) [15], balance and gait ability of elderly people [16] and pain of patients with chronic back pain [17]. Although equestrian simulator training has all these benefits, it has however not yet been widely used by equestrians [12]. This can be explained by the fact that there are limited simulators for use, and they are expensive which makes them not accessible to train with. In addition, the relation of the performance on the simulator with the physical capacities of the rider is not known.

Therefore, in this study we want to compare rider performance (based on balance symmetry, rein force) on the simulator between novice and experienced competitive riders and investigate if more routinely applicable physiotherapeutic screening tests have the potential to determine the physical capacities of the rider. This way, we can investigate which physical factors are most discriminative between novice and experienced riders and are important to determine rider performance. We hypothesize that (1) experienced riders show a more symmetrical and balanced position compared to novice riders and that (2) experienced riders score higher on the standardized physiotherapeutic tests.

Materials and methods

Participants

22 dressage riders were included in the present study and divided in a novice and expert group. Dressage riders were included when: age 18-50 years, no history of disorders that can influence rider performance, no neurological disorders. Participants were included in the novice group (G1) when they participated at most in regional competition at level initiation/B in the last five years or in the expert group (G2) when they participated in national or international competition in the last five years.

All subjects signed a written informed consent prior to the study and all study procedures were approved by the local ethical committee (S63654).

Experimental design and procedures

The measurement session consisted of two parts: the biomechanical simulator analysis and the physiotherapeutic screening. The tests were conducted in a random order and all tests were performed while wearing standard equestrian clothing.

Biomechanical simulator analysis

A sequence of all nine types of gaits which are covered in dressage was assessed. The same gaits were imposed to all different participants through the Racewood® Eventing Simulator [12, 15]. This simulator is able to mimic the reaction of a real horse through an independently moving body, neck and head and was previously developed for screening and training riding skills by simulating horse movements (Figure 1a, b). The pressure under the saddle was measured using four pressure sensors under the saddle in each corner (left front, left back, right front, right back) and rein force was measured by a force sensor in each rein (Racewood® Eventing Simulator, 80 Hz). At the same time the posture of the rider was recorded using a video camera (Sony® Handycam, 50i) in the sagittal plane from the left side of the horse.

Before getting on the simulator, white tape markers were placed on the hip, shoulder, elbow, ankle, and knee on the left side of the rider for the video analysis (Figure 2). Next, the rider mounted the simulator, and the stirrups were altered to the desired length. The rider was instructed to maintain a constant force on the reins (“stable rein contact”) and to follow the movements of the simulator without giving aids. After a two-minute standardized habituation in three gaits (collected walk, medium trot, collected canter), the actual measurement was performed: the nine gaits of dressage were recorded for 30 seconds each. The different gaits were assessed in the following order: halt – collected walk – medium walk – extended walk – collected trot – medium trot – extended trot – collected canter – medium canter – extended canter. To make sure that no feedback was provided to the rider, the output screen of the simulator was covered.

(a) (b)

Figure 1. Photograph of the simulator with (a) and without (b) rider on

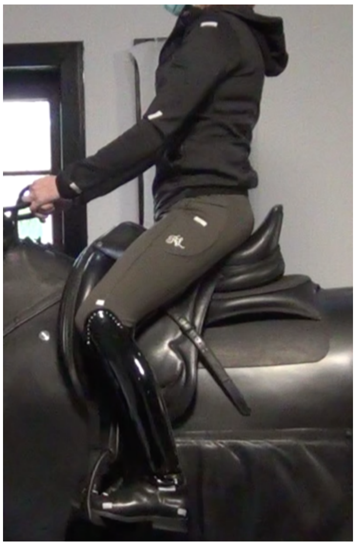


Figure 2. Photograph of a rider with the white tape markers placed

Physiotherapeutic screening

The screening consisted of 6 physiotherapeutic tests which evaluate physical capacities that were previously identified as important for rider performance [1, 2, 7, 10, 18-21]. All riders performed the tests in the same order and all tests were executed barefoot.

First, the **Lateral Side-Bending Flexibility Test** [22] to test trunk flexibility (Figure 3b). For this test, the rider stood with the back against the wall and the distance between the distal end of the hand and the ground was measured. Then the rider reached as far as possible in lateral flexion and the distance between the hand and ground was measured again. The difference between both measures was the score of the test. Secondly, the **Sit-and-Reach Test** [23] to evaluate lumbar and hamstring flexibility (Figure 3a). The rider sat on the ground with legs stretched out straight ahead. The soles of the feet were placed flat against a box and the hands were put on top of each other. The rider reached as far as possible forward along the measuring line. The score was the maximum reaching distance (cm) with the zero-mark 15cm proximal to the level of the feet. The riders performed this test 3 times and the best score was the score taken for analysis. Thirdly, the **Plate Tapping Test** [23] to evaluate upper body reaction time and coordination (Figure 3d). The rider was standing in front of a table with a board on it. The board displayed two discs with their centers 60 cm apart and a rectangle equidistant between both discs. The rider placed the non-preferred hand on the rectangle while the other hand tapped the discs back and forth over the hand in the middle as many times as possible. The score was the time needed for 50 taps (s). Fourthly, the **JAMAR® Hand Grip Strength Test** [22, 24, 25] to measure hand grip strength, which can be seen as a representative of total body strength and strength symmetry [25]. For this test, the rider was asked to squeeze a JAMAR® hydraulic dynamometer as strong as possible while sitting in a chair and keeping the elbow in a 90° flexed position. The rider performed this test three times at both sides. The composite score of each side was the average force scored of each side. Fifthly, the **Star Excursion Balance Test (SEBT)** (Figure 3c). This test provides objective measures to differentiate deficits and improvements in dynamic postural stability, neuromuscular control, muscle strength and coordination in the lower extremity in equestrians [20, 26, 27]. It was constructed by placing three tape measures in three directions (anterior, posteromedial, posterolateral) from the center. Both posterior tape measures formed a right angle and were positioned 135° from the anterior pipe. The rider placed one foot on the center with the big toe right on the center. While placing both hands on the hips, the other foot reached as far as possible along the measure tapes. When the rider fell, took weight on the reaching foot, or removed the hands from the hips, the test was repeated. The test was executed three times in every direction at both sides. The composite score in each direction was the average reach distance (cm) in each direction.

Finally, the **Upper-Quarter Star Excursion Balance Test (UQSEBT)** was performed to evaluate core strength, stability, scapular mobility and thoracic rotation [28, 29]. This test used the same setup as the SEBT, but now with a medial direction instead of the anterior direction (Figure 3c). The rider maintained a push-up position with feet at shoulder width apart and reached with the reaching hand as far as possible in the three directions (medial, inferolateral, superolateral) while placing the thenar of the contralateral hand in the center. The test was executed three times in every direction at both sides. The composite score in each direction was the average reach distance (cm) in each direction.

Both the SEBT and UQSEBT outcomes were normalized for limb length by dividing the composite score by lower limb and limb length, respectively and then multiplied by 100. Lower limb length was measured by the investigator with the rider in supine position by measuring the distance (cm) from the greater trochanter of the hip towards the medial malleolus of the leg. For measuring upper limb length, the rider stood in anatomical position while the examiner identified the C7 vertebra. Subsequently, the rider was asked to abduct the arm to 90°. The examiner then measured the distance between C7 and the distal end of the arm.

(a) (b)

(c) (d)

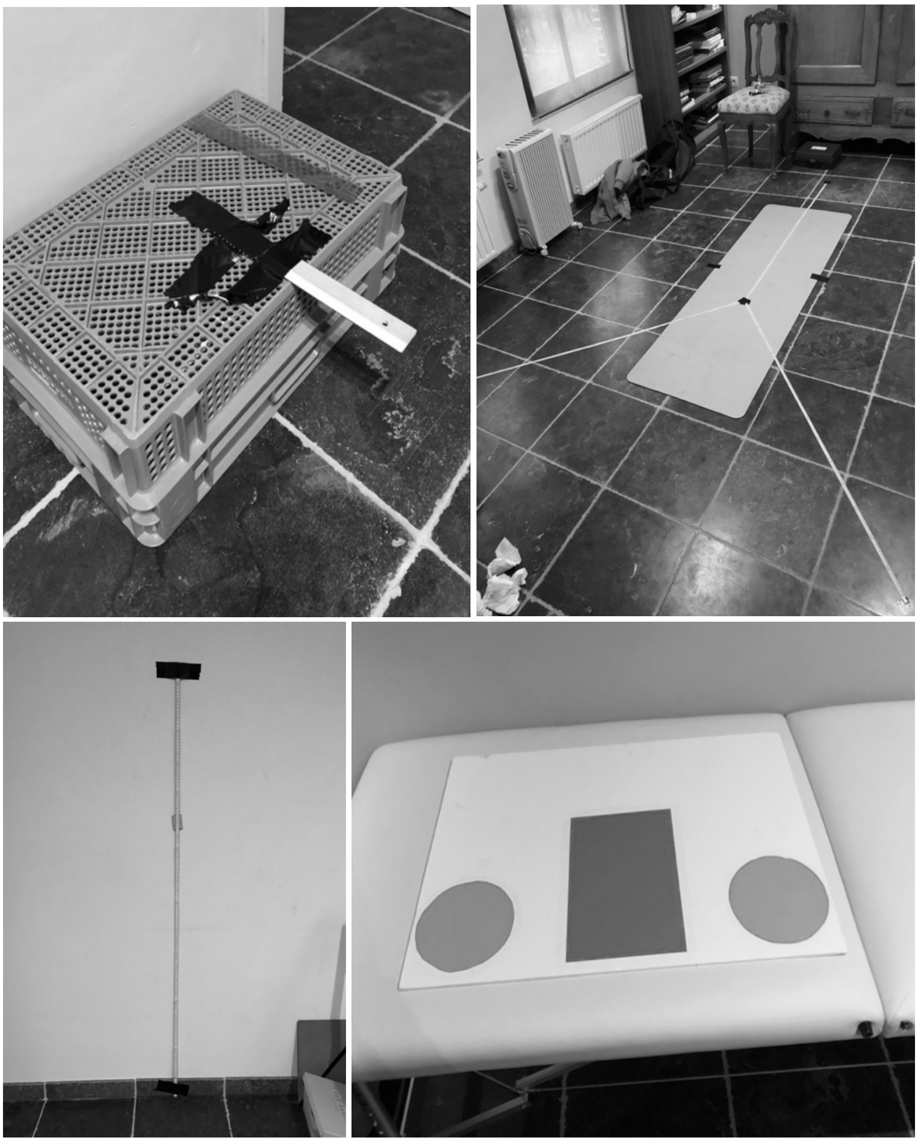


Figure 3. Photographs of physiotherapeutic screening test setup: Sit-and-Reach Test (a), SEBT and UQSEBT (b), Lateral Side-Bending Flexibility Test (c) and Plate Tapping Test (d)

Data analysis

Simulator analysis

The simulator provided pressure measurements for each pressure sensor and the applied force on each rein over time. From this data, eight parameters were calculated and averaged over the total duration of each gait. From the four pressure sensors the center of pressure (COP) was calculated, next COP excursion in the anteroposterior and mediolateral direction and the area of the smallest ellipse that covers 95% of the COP diagram was calculated. From the rein force sensors: the average force as well as the variability on each side was determined as well as the symmetry in rein force. Average symmetry was calculated from the ratio of the left to right rein force.

Video analysis

Video images were processed using the motion analysis program Kinovea (version 0.9.3). The middle 5 cycles in each gait were extracted and analyzed. The position of the markers placed on the rider and the middle of the hand were tracked semi-automatically. Marker trajectories in 2D were first filtered using a moving average filter and subsequently, relative joint angles (Figure 4) were calculated. From these joint angles the range of motion (ROM) and variability were calculated for each joint and gait separately. These parameters were determined for the hip, knee, shoulder, elbow, and trunk.

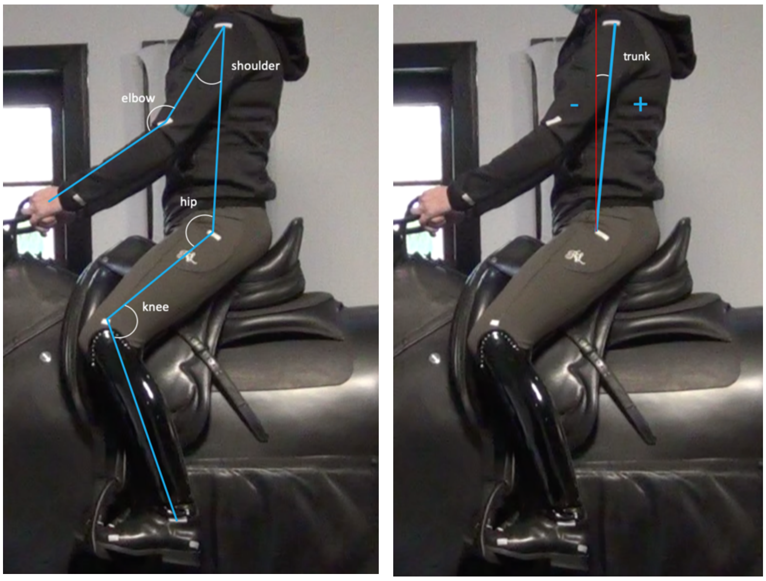


Figure 4. Relative joint angles measured in this study

Statistical analysis

For each gait and for each parameter, group means, and standard deviations (SD) were calculated and compared between groups. Equality in variance was assessed through the F-test. To determine significant differences between both groups two-tailed t-tests were used ($p < .05$). All statistical tests were conducted in Microsoft Excel (version 16.16.17, Microsoft, Washington, USA).

Results

Twenty female and two male dressage riders were included and divided in two cohorts depending on their competitive level, twelve riders were included in the novice group and ten riders were included in the experienced group. Riders in the experienced group had significantly more training hours/week compared to the novice group. No further significant differences in participant characteristics were observed between groups. A more extended overview of the participants' demographics can be found in Table 1.

Table 1. Participant demographics

Group	*N*	*Age*	*Height (cm)*	*Weight (kg)*	*Years of riding experience*	*Hours of training/week*
Novice riders (G1)	12	26,8 ± 9,6	166,4 ± 5,2	61,6 ± 10,9	12,8 ± 5	3,2 ± 2,8
Experienced riders (G2)	10	27,8 ± 8	167,1 ± 8,1	65,7 ± 9,8	20,4 ± 6,3	14,6 ± 14,4

Simulator analysis

Experienced riders showed significantly less variability in both left (p = 0.002) and right (p = 0.021) rein force in medium canter compared to novice riders. There was a trend towards less average symmetry in rein force (p = 0.088) in the experienced rider group compared to the novice riders. No further significant differences between groups were found in other gaits or parameters obtained from the simulator. The results of the rein parameters in each gait are shown in Figure 5.

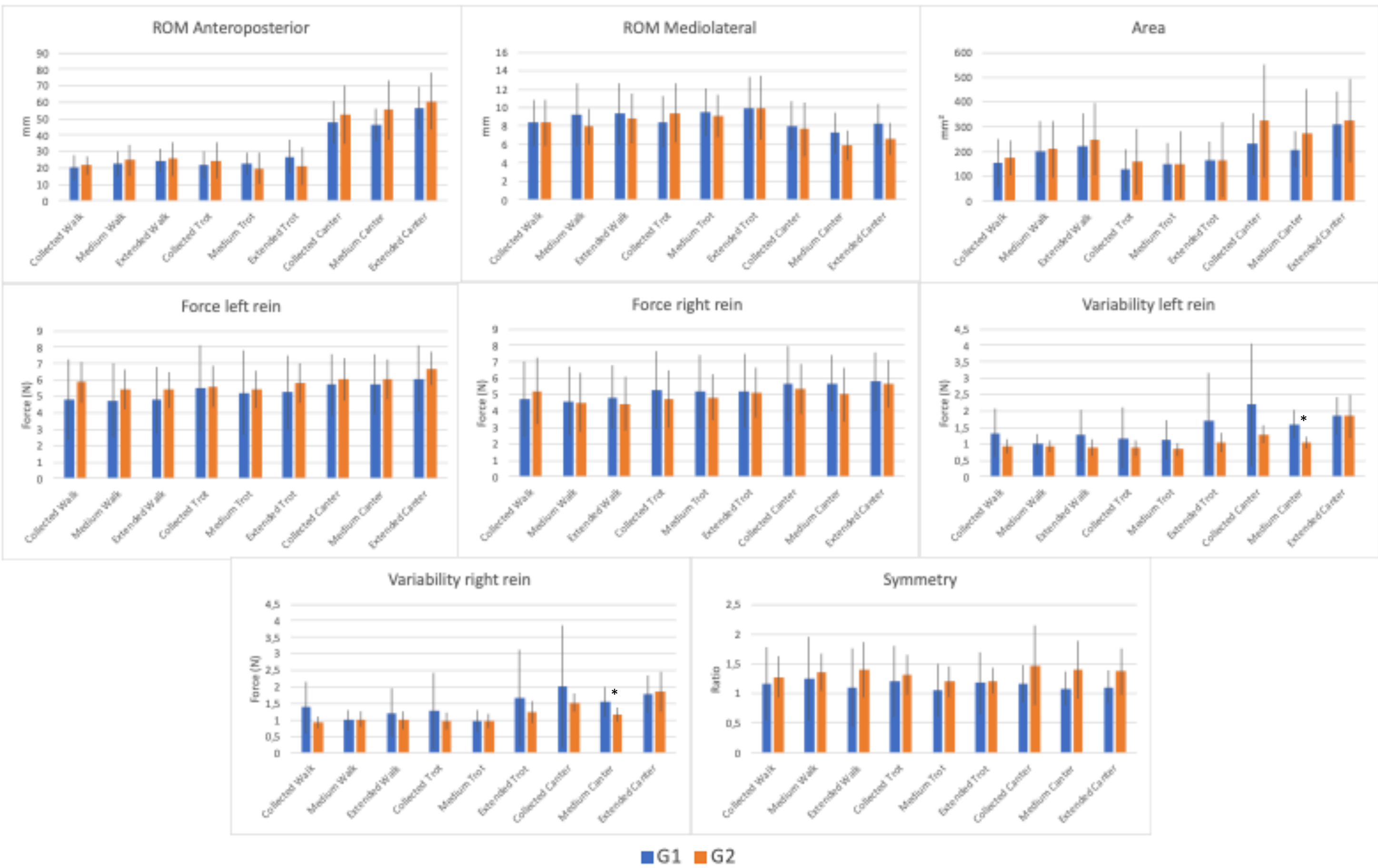


Figure 5. Charts with rein parameters obtained on the simulator during each gait

Video analysis

The average angle of the shoulder was significantly higher in experienced riders compared to novice riders in all gaits ($p < .05$), except during extended walk ($p = 0.054$) (Figure 6). This means the experienced riders positioned their arms more in front of their body instead of keeping them close to the trunk. During medium walk, the experienced rides also showed a significantly larger angle in the elbow ($p = 0.022$), meaning they had more extended elbows. No further significant differences in average joint angles were found between groups (Table 2).

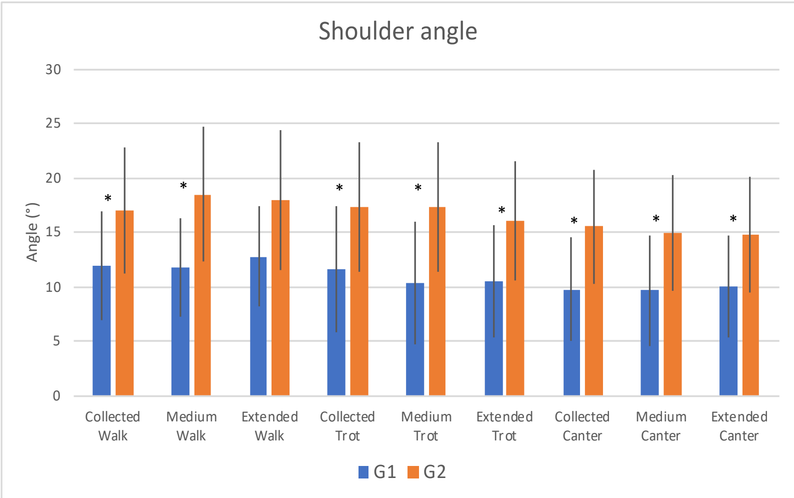


Figure 6. Average shoulder angle (°) during each gait of both groups

	Knee		*Hip*		*Shoulder*		*Elbow*		*Trunk*	
	G1	G2	G1	G2	G1	G2	G1	G2	G1	G2
Collected walk	129,6 ± 6,2	130,4 ± 9,5	149 ± 3,9	147,3 ± 7,8	11,9 ± 5,1*	17 ± 5,8*	144,6 ± 8,8	150,7 ± 6,9	5,2 ± 2,3	4,4 ± 4
Medium walk	129 ± 7	129 ± 10	150,6 ± 5	148,8 ± 8,3	11,8 ± 4,6 *	18,5 ± 6,2*	145,1 ± 4,6*	153,3 ± 6*	4,9 ± 2,8	3,9 ± 3,8
Extended walk	129,5 ± 6,9	129,8 ± 10,7	150,1 ± 4,4	148,8 ± 8,5	12,8 ± 4,5	18 ± 6,4	146,7 ± 10,3	152,5 ± 6	4,1 ± 2,5	3,7 ± 3,7
Collected trot	129,1 ± 6,8	129,3 ± 9,6	149,2 ± 6,8	147,2 ± 8,2	11,6 ± 5,8*	17,3 ± 5,9*	145,1 ± 9,7	149,7 ± 6,9	5,8 ± 4	4,8 ± 4
Medium trot	128,1 ± 6,5	129,1 ± 10,1	150,8 ± 4,9	148,3 ± 8,5	10,3 ± 5,7*	17,3 ± 5,9*	143,3 ± 10,6	149,4 ± 7,3	6,2 ± 3,6	5,1 ± 4,1
Extended trot	128,4 ± 8	128,4 ± 10,3	150,5 ± 4,7	148,8 ± 8,9	10,5 ± 5,1*	16 ± 5,5*	143,1 ± 10,7	148,1 ± 7,2	6,1 ± 4	5,5 ± 4
Collected canter	125,9 ± 6,1	126,7 ± 10,3	145,7 ± 4,1	143,4 ± 8,1	9,8 ± 4,8*	15,5 ± 5,3*	138,9 ± 9,9	143 ± 7,1	4,6 ± 3,2	2,7 ± 3,5
Medium canter	127,3 ± 7,7	126,1 ± 10,4	147 ± 3,4	144,4 ± 8,5	9,7 ± 5,1*	14,9 ± 5,4*	138,9 ± 10,1	143,5 ± 6,2	4,1 ± 2,8	2,7 ± 3,2
Extended canter	127,8 ± 8,3	125,5 ± 10,6	146 ± 4,3	142,4 ± 8,7	10 ± 4,7*	14,8 ± 5,4*	137 ± 11,3	141,1 ± 6,7	4,3 ± 3,5	1,4 ± 3,6

Table 2. Average angles (°) during each gait of both groups, (mean +- standard deviation given)

The experienced riders had a significantly smaller ROM in the knee during collected walk ($p = 0.033$) and in the trunk during collected canter ($p = 0.012$) compared to the novice riders (Figure 7). No further significant differences in ROM were found in other angles between groups. Subsequently, the experienced rides showed significantly less variability in the trunk angle during collected canter (p =

0.034) and showed a trend towards less trunk variability during medium canter (p = 0.069). Average trunk variability of each group is displayed in Figure 8.

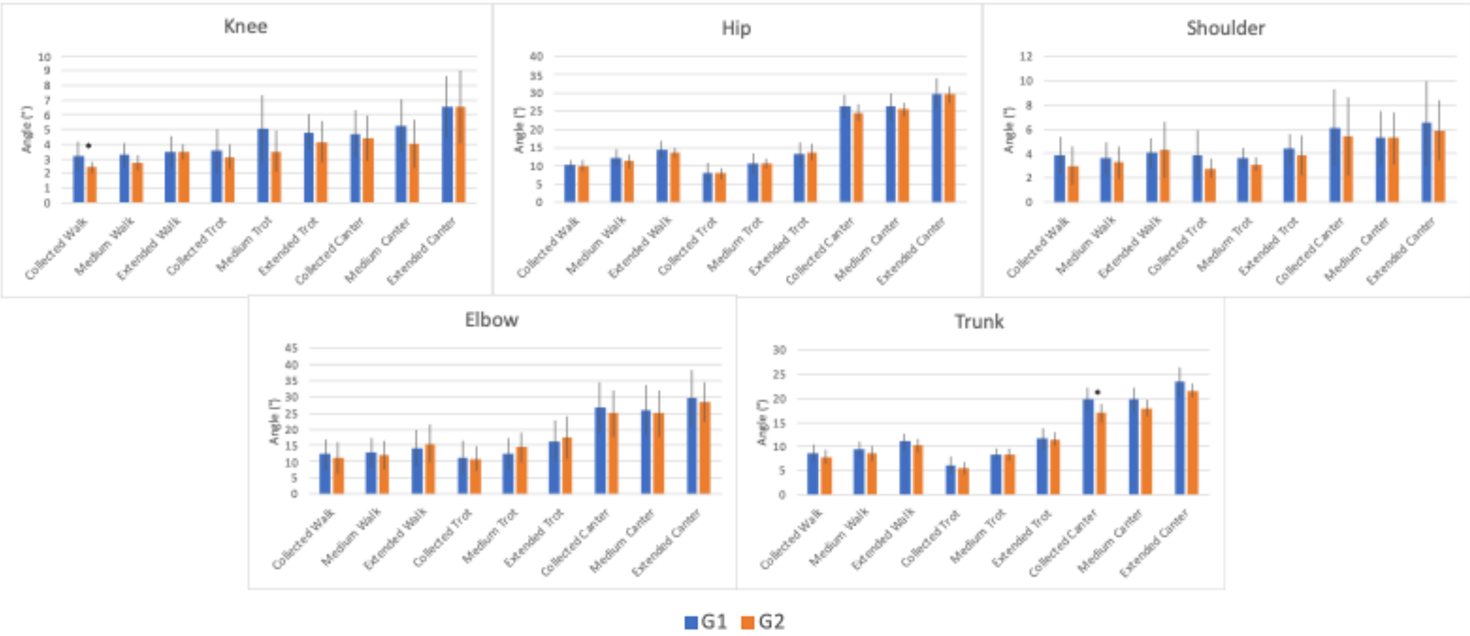


Figure 7. Average range of motion (°) in each angle during each gait of both groups

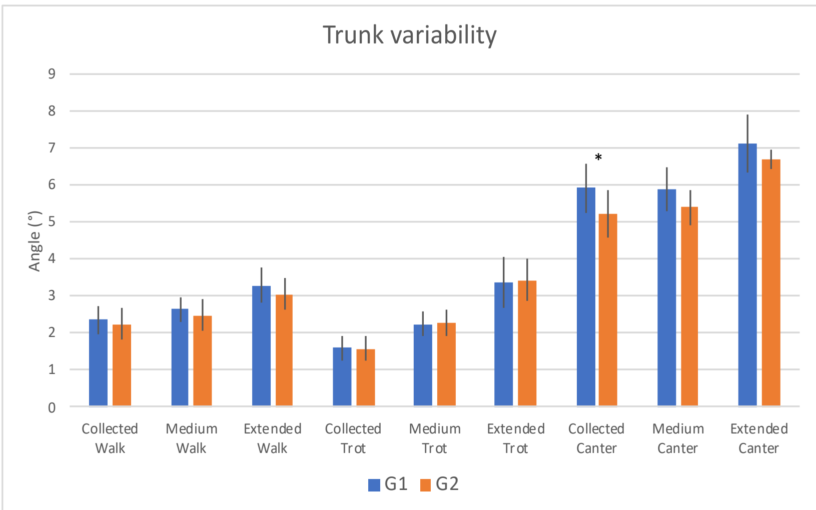
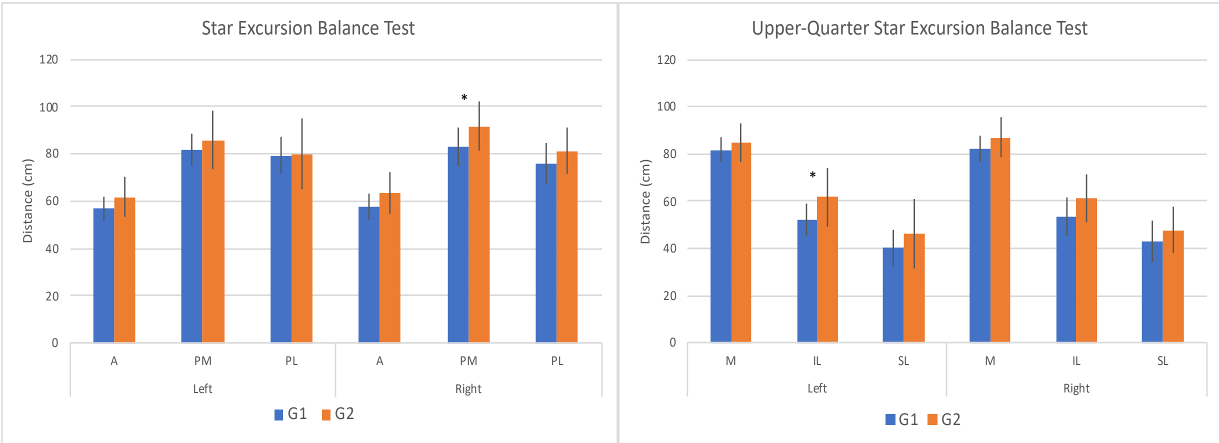


Figure 8. Average trunk variability (°) during each gait of both groups

Physiotherapeutic screening

Experienced riders scored significantly better on the SEBT in the posteromedial direction (91,8 ± 10,3 cm vs 82,7 ± 8,1 cm; $p = 0.039$) and showed a trend in the anterior direction (63,5 ± 8,6 cm vs 57,4 ± 5,6 cm; $p = 0.068$) with the right leg (Figure 9a). After normalizing for limb length, the experienced riders had the tendency to score better in the posteromedial direction ($p = 0.077$). In addition, the experienced riders achieved significantly better results on the UQSEBT in the inferolateral direction with the left arm (61,7 ± 7,3 cm vs 52 ± 10,7 cm; $p = 0.031$) (Figure 9b), even after normalizing for upper limb length ($p = 0.049$). No further significant differences between groups were observed in the other physiotherapeutic screening tests (supplementary material).

(a)



(b)

Figure 9. Chart with average distances scored on SEBT (a) and UQSEBT (b) in each direction

Discussion

Until now there is only limited research on what factors distinguish expert riders from novice riders and therefore predispose riders to a better performance. Based on the official dressage guidelines of the Fédération Equestre International (FEI) there is a general consensus on the ideal dressage rider position stating the following [2-4, 8, 9, 14, 30, 31]: "All the movements should be obtained with imperceptible aids and without apparent effort of the athlete. The athlete should be well-balanced, elastic, sitting deep in the centre of the saddle, smoothly absorbing the movement of the horse with his loins and hips, supple thighs with the legs steady and stretched well down. The heels should be the lowest point. The upper part of the body should be tall and supple. The contact should be independent from the athlete's seat. The hands should be carried steadily close together, with the thumb as the highest point and a straight line from the supple elbow through the hand to the horse's mouth. The elbows should be close to the body. All of these criteria enable the athlete to follow the movements of the Horse smoothly and freely." Therefore, the current study compared novice and experienced competitive dressage riders in a controlled environment using a Racewood® Eventing Simulator. We evaluated pressure under the saddle, rein force, joint angles in the sagittal plane as well as their physical capacities by standardized physiotherapeutic screening tests and compared results between both groups.

To have a good communication with the horse, the rider should be able to follow the horse's movements without being dependent on the usage of the reins to stay balanced [2, 9, 32]. The reins form a direct connection between the bit within the oral cavity of the horse, one of the most important means of communication between the rider and the horse, and the hands of the rider. By learning the horse to react to subtle hand movements of the rider and to give a specific response, complex exercises which are part of the higher levels of dressage can be taught. When the rider is not able to maintain a continuous force on the reins, also referred to as "stable rein contact", the horse receives disturbed signals from the bit, leading to miscommunication and possibly to lower performance during a dressage test [2, 3, 9, 14, 32]. In our study, on the simulator, the novice riders showed significantly more variability in rein force on both sides during medium canter. This result confirms our hypothesis that experienced riders would have a more balanced and stable hand position on the simulator. Subsequently, the experienced riders showed less trunk variability in different gaits and had a smaller range of motion (ROM) in the trunk angle during collected canter and in the knee during collected walk compared to novice riders. These findings are in line with previous studies reporting that advanced riders have less ROM in the trunk, elbows, and knees, suggesting that a more stable and calmer posture is an important factor for good riding performance [4, 14]. Another interesting fact is that most differences between groups were found in the collected gaits. Lower level dressage tests only include working gaits, a pace between the collected and medium gait [30]. Collected gaits ask more finesse and balance from the rider, possibly explaining the significant differences between groups in these gaits, even in the controlled environment of the simulator.

Horses naturally distribute their body weight slightly more on their forehand than their hindquarters, positioning their center of mass (COM) at the lowest point of the back in the saddle region [33]. Dressage riding asks for the horse's ability to lower and engage its hindquarters to bring its COM more back for the benefit of the lightness and mobility of its forehand, also referred to as “collection” of the horse, with the aim to further develop and improve the balance and equilibrium of the horse, which has been displaced by the additional weight of the rider. Higher level dressage exercises need more “collection” of the horse. The rider achieves this by using seat and legs to engage the hindquarters and at the same time keeping the hands in an upward guiding position to make the hindlegs step forward under the body. However, in this position it is more difficult to maintain a stable position with the arms and hands [30]. In current study, experienced riders showed a significantly larger shoulder angle in the sagittal plane in all gaits, except during extended walk, indicating that novice riders positioned their hands lower on the neck of the horse, closer to the saddle and held their arms closer to their body. Potentially novice riders seek more stability with their hands by squeezing the arms closer to the body and by placing their hands close to the neck of the horse and the saddle. The experienced riders on the other hand position their hands higher and more in front of the riders’ body as this gives the rider more space to follow the horse’s movements and to manipulate the reins in a subtle way to give signals to the horse. These findings are in line with a previous study that compared experienced and novice rider kinematics on a simulator. Moreover, they found that when the novice rider group was trained over time, their shoulder angle became more similar to the experienced rider group, hence larger, over time [14]. In the context of collection, this difference in hand positioning demonstrates the dissimilarity in skill level of both groups where the experienced riders tend guide the horse more towards engagement of the hindquarters, even when the horse is replaced by a simulator.

In contrast with several studies which found significant differences in postural strategy and technique of riders of different skill levels during a riding session on a ridden horse [3, 4, 14], we found no further significant differences between groups on the simulator. Some studies found significant skill-dependent differences in rider kinematics on a simulator, but in these studies the comparison was made between experienced competitive dressage riders and riders with no or very limited riding experience [14, 34]. In contrast, in our study, the riders were all competitive dressage riders, meaning that even the novice rider group already mastered basic rider skills needed to maintain stability on a horse. These findings align with previous studies that demonstrated that competition level was not significantly related to static pelvic posture, dynamic mean pelvic tilt, or pelvic range of motion while riding on a simulator [34].

The fact that no additional significant differences could be found can be explained by the fact that our study was conducted in a highly controlled environment created by the simulator that simplifies the complex task of riding a horse and several studies show that riding a real horse differs greatly from riding a simulator [12, 14, 34-37]. Indeed, the simulator has a smaller dorso-ventral and medio-lateral displacement in combination with a greater cranio-caudal displacement compared to a real horse. In addition, the cranio-caudal displacement of the simulator is around 180° out of phase with that of a horse [37]. Furthermore, riding a horse induces a more challenging proprioceptive environment and is physically more demanding than riding a simulator [12]. Ridden horses, in contrast to the simulator used in this study, may at any time act in an unpredictable way which requires an immediate and unforeseen response of the rider [12, 34]. Furthermore, riding a horse induces a more challenging proprioceptive environment and is physically more demanding than riding a simulator. These findings indicate that the riding situation on a horse is much more complex than on a simulator. The simulator is a safe and useful tool to correct a rider's seat in addition to ridden horse trainings, but it cannot fully replace the training on a ridden horse [12, 34, 35, 37].

In the second part of our study, we investigated the physical capacities of the riders using standard physiotherapeutic screening tests. Out of the six tests conducted, significant differences were found for the Star Excursion Balance Test (SEBT) and the Upper-Quarter Star Excursion Balance Test (UQSEBT). The other tests evaluating reaction time, hand grip strength, and analytical flexibility showed no clear differences. The significant differences found in the SEBT and UQSEBT, are in concordance with previous studies which showed that flexibility, balance, and muscle strength are indeed important physical factors for rider performance [1, 2, 7, 10, 18, 20, 21]. The SEBT is a widely used test for athletes and healthy active adults to evaluate muscle strength, flexibility, dynamic postural control, and proprioception [20, 26, 27]. Equally, the UQSEBT is a challenging test used to evaluate core strength, stability, scapular mobility, and thoracic rotation in athletes and healthy active adults [28, 29]. In addition, these results are in relation to the more stable posture and hand position of the experienced riders observed on the simulator compared to the novice riders in this study. This suggests that, to have a good dressage seat on the horse and therefore a better rider performance, the rider needs to have a good balance, dynamic postural control, and muscle strength. All tests conducted in the present study were static and analytical, except for both the SEBT and the UQSEBT, indicating that equestrian sport is a dynamically complex sport, challenging several physical factors at the same time for good performance. However, since the reported differences of these two physiotherapeutic tests are not consistent in all directions and each limb, more research is needed on this topic.

It is important to evaluate the findings of our work in the light of the following limitations: First, our riders were mainly young female riders. Only two male riders were included, and they were both part of the experienced rider group. Since this is a specific population, caution should be taken not to over generalize these findings. Second, all riders used a generic saddle on the simulator, which was not fitted to the individual rider, although the stirrups were altered to the desired length. Saddle characteristics such as seat slope may have an effect on the rider’s joint angles and spinal curves [2, 31, 34, 38].

In conclusion, the current study shows that “stable rein contact” is the main difference between novice and experienced competitive dressage riders on the simulator. Further, the higher shoulder angle of experienced riders and the novice riders, indicates better ability to maintain a dynamically stable hand position and to guide the horse towards “collection”. Experienced riders had a more stable posture on the simulator as indicated by the reduced trunk variability and smaller trunk and knee ROM in the collected canter and collected walk respectively. These kinematic differences underly their enhanced capability of maintaining a continued and constant force on the reins. Finally, our results of the physiotherapeutic screening suggest that both the SEBT and the UQSEBT could be reliable tools in equestrian sports to screen and follow up athletic ability and ultimately improve rider performance, but further research is needed on this specific topic.

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Supplementary material

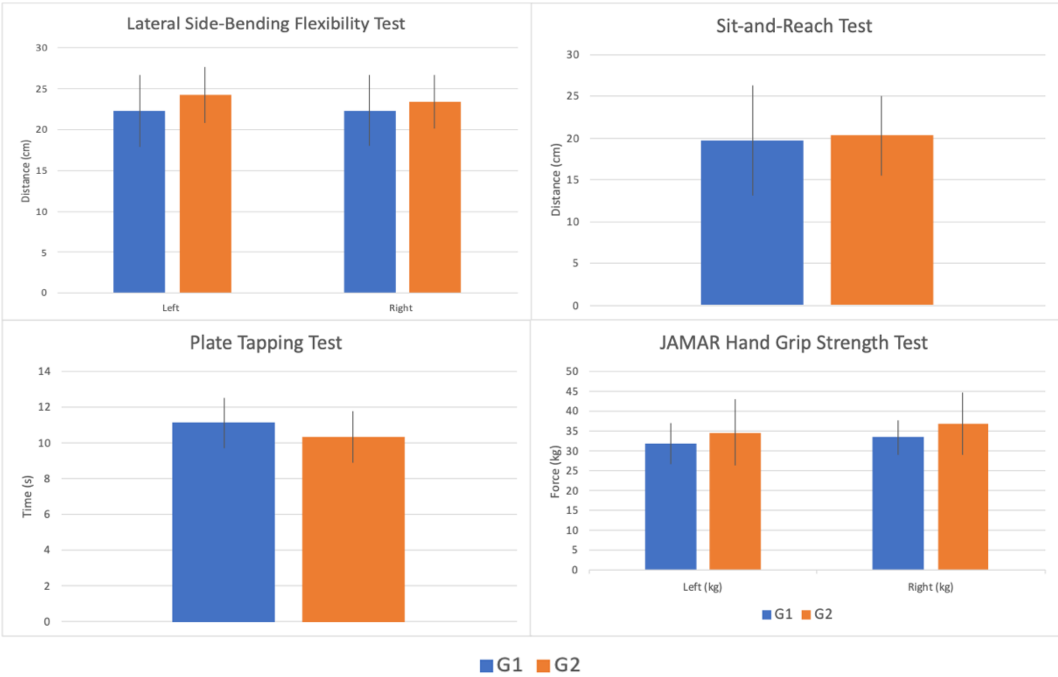

Figure 10. Chart with average scores on the physiotherapeutic screening tests of both