KINEMATIC ANALYSIS BY GENDER IN DIFFERENT JUMP TESTS BASED ON A SMARTPHONE INERTIAL SENSOR

ANÁLISE CINEMÁTICA POR GÊNERO COM BASE NO SENSOR INERCIAL DE UM SMARTPHONE EM DIFERENTES TESTES DE SALTOS

ABSTRACT

Introduction: Vertical jump tests can be used as estimators of muscular power, physical capacity, motor development and functional capacity. The ability to jump can be analyzed with different methods, including the use of inertial sensors. Objective: To describe and analyze kinematic characteristics using the inertial sensor integrated into the iPhone 4S® and jump contact mat variables in the squat jump (SJ) and countermovement jump (CMJ) tests, and to determine the interaction between kinetic and kinematic variables. Methods: A cross-sectional study was conducted with 27 healthy young adults. The primary outcome measures were linear acceleration, flight time, contact time, jump height and dynamometry of the knee extensors. Spearman’s rho was used to investigate the correlation between variables. The Mann–Whitney U rank-sum test was used for the analysis of intergender variance. Results: The greatest difference between groups (gender) was in the dynamometry variables (p<0.001) and contact mat variables (p<0.001). Between the jump tests, the greatest difference between groups (gender) was in the CMJ test (p<0.001). Conclusion: The inertial sensor embedded in the smartphone demonstrated a correlation with the jump mat and the dynamometry. Finally, the higher kinetic and kinematic scores observed in the jumps performed by male participants than in those performed by female participants suggest that they can be used to better characterize their jumping profile. Level of Evidence IV; Diagnostic Studies - Investigating a Diagnostic Test.

Keywords: Acceleration; Biomechanical Phenomena; Athletic Performance.

RESUMO

Introdução: testes de saltos verticais podem ser utilizados como estimadores de potência muscular, capacidade física, desenvolvimento motor e capacidade funcional. A capacidade de pular pode ser analisada através de diferentes métodos, incluindo o uso de sensores inerciais Objetivo: descrever e analizar características cinemáticas, usando o sensor inercial integrado no iPhone 4S®, e variáveis de contato na tapete de saltos, nos testes de salto com agachamento (SA) e salto de contraposição (SCP), e determinar a interação entre variáveis cinéticas e cinemáticas. Método: foi realizado um estudo transversal, envolvendo 27 adultos jovens saudáveis. As principais medidas de resultados foram aceleração linear, tempo de vôo, tempo de contato, altura de salto e dinamometria do joelho. Foi utilizado o Rho de Spearman para a investigação da correlação entre variáveis. O teste Mann-Whitney U de soma de classificação foi utilizado para a análise de variância entre gênero. Resultados: a maior diferença entre os grupos (gênero) estava nas variáveis de dinamometria (p<0.001) e variáveis de contato (p<0.001). Entre o teste de saltos, a maior diferença entre grupos (gênero) estava no teste SCP (p<0.001). Conclusão: O sensor inercial embutido no smartphone demonstrou uma correlação com o tapete de saltos e a dinamometria. Por fim, os scores mais altos (cinéticos e cinemáticos), observados nos saltos dos indivíduos do gênero masculino em comparação com o feminino, sugerem que podem ser usados para melhor descrever o seu perfil de salto. Nível de Evidência IV; Estudos diagnósticos - Investigação de um exame para diagnóstico.

Descritores: Aceleração; Fenômenos Biomecânicos; Desempenho Atlético.
INTRODUCTION

There are investigations focused on the changes in anthropometric characteristics during the evolution and growth in boys and girls. Other works reported sex differences in jump height with larger increases in height for boys compared to girls at puberty. Their results exhibited a highly significant difference in jump performance between genders from the age of 14 years. However, the observed jumping performance changes remain questionable since the relationships between physical performance and anthropometric characteristics between young healthy adults were not studied.

Various approaches can be described in order to evaluate functional capacity; for instance, vertical jump tests. Moreover, the latter could also be used as a predictor of anaerobic capacity, motor development and athletic skills in sports. Other research accounts that the vertical jump test could serve as a measuring tool to evaluate functional capacity in the elderly and young population. Several calculation procedures can be defined so as to assess functional capacity, including vertical launch velocity rate, flight duration, output force, and the trajectory displacement of the body centre of mass (COM). Force platform, video-analysis systems, photoelectric cells and contact mats have been a few of the typical determining methods to estimate these variables.

Moreover, innovative tools have recently been launched for the purpose of human motion research, for example inertial sensors, small and handy appliances that offer solutions to the inconveniences of the standard tools for human motion examination. In a few studies, accelerometer components have been applied to calculate vertical jump capacity. These tools identify the acceleration highest values registered while carrying out the routine of vertical jumps.

Nowadays, the modern generation of smartphones are typically manufactured with inertial sensor components and subcomponents, such as accelerometers and gyroscopes, being able to register position as acceleration and inclination. Subsequently, several applications compatible with various operating systems have been developed, being able to show, record and transfer inertial sensor information. Many of the uses of these applications include a great capacity for tracing human motion variables for both investigation and medical uses. Many of these mobile applications are being implemented for use in statuses typical determining methods to estimate these variables. Anthropometry. Weight, height and body mass index (BMI) were determined from the vertex to the soles of the feet. It is measured with the subject standing in an anatomical position with the occipital region, back, gluteal region and heels in contact with the height rod. The subject takes a deep breath at the time of measurement. The weight was recorded with the subject barefoot and in underwear. The body mass index (BMI) was calculated by dividing weight in kilograms (kg) by height in metres squared (m2).

Vertical jump performance. Participants performed three trials of the SJ and CMJ (with arm swing modality) jump tests described by Bosco. All the participants completed a 10-minute warm-up consisting of cycling on a cycle–ergometer. After the warm-up, the participants were instructed on how to perform the CMJ and the SJ. A Globus Ergojump Thesys contact mat was used to record the height (centimetres) and flight time (seconds) through the CMJ with arm swing and SJ tests. The Globus Ergojump contact mat was validated in a prior study. All the participants performed three attempts at each jump (CMJ and SJ). The CMJ test was performed with the subjects starting from an upright position, performing a rapid downward movement followed by a dynamic complete extension of the lower limbs, the subject performing a quick flexion and extension of the knee joint with minimal stops between eccentric and concentric phases. CMJ was validated in a previous study. For the SJ test, all participants were instructed to maintain a static first position with hands on hips and knees in flexion (90° degrees). The subject performed the jump without any preparatory movement.

Kinematic variables. Linear acceleration was measured along three orthogonal axes using the iPhone 4S inertial sensor, which incorporates a three-axis gyroscope, accelerometer and magnetometer. The smartphone was fixed at L5-S1 level attached to a belt. The orientation and movement of the sensors are presented as axes (x, y, z). With the sensor
aligned with the anatomical axes of the trunk (fixed at L5-S1), the z axis in the smartphone is around the anteroposterior (AP) accelerations, the x axis in the smartphone is around the mediolateral (ML) accelerations, and the y axis in the smartphone is around the vertical (VT) accelerations. From the accelerometer were obtained: maximum peak, minimum peak, mean and SDs of accelerations in the three axis of movements (AP, ML and VT). In addition, maximum peak, minimum peak, mean and SDs of the vector sum (VS) accelerations (VS = √x² + y² + z²) were obtained. Data were obtained for analysis through SensorLog®️, Bernd Thomas®️ from Apple®️ AppStore®️. The recording rate was set at 30 milliseconds.

The recordings were stored in the internal memory of the smartphone and were then sent via email for offline processing. A previous study14 exhibited that the smartphone (iPhone) inertial sensor subunit (accelerometer) was accurate against a gold standard (ICC r>0.98). The accelerometer embedded into iPhone 4®️ was accurate and reliable in measuring and quantifying physical activity in the laboratory setting.14

Maximum isotonic strength. Knee extensor isotonic muscle strength was evaluated by bilateral dynamometry through the digital manual dynamometer POWERTRACK®️ JtechMedical. This tool incorporates a load cell affixed to the distal end of the leg of the subject. The dynamometer has a digital display that shows the force applied to the load cell in newtons and records the peak of each attempt. The validity of this dynamometer has been demonstrated, with an interclass correlation coefficient (ICC) ranging from 0.72 to 0.85.15

The participant is placed in a sitting position on a stretcher, his hands resting on his legs and feet hanging off the ground. The examiner places one hand to stabilize the subject’s leg and the other hand to support the load cell on the subject’s distal third tibia. Starting from 90° knee flexion, the subject performs a knee extension resisted by the examiner with the load cell. A full extension must be avoided, with the knee flexion reaching 5°. The maximum peak force is recorded in the digital dynamometer. The test was performed three times for each subject, with a 2-minute break between tests; the highest value was taken.

Statistical analysis
A database was created from anthropometric data, the inertial sensor variables, the jump test variables and maximum isotonic strength of the knee extensor variables. The Kolmogorov–Smirnov test was used to determine normal distribution of the variables. Descriptive statistics were performed with measures of central tendency and dispersion of the variables studied. Spearman’s rho was used for the investigation of the correlation between the kinematic variables, vertical jump variables and maximum isotonic strength variables in SJ and CMJ. Furthermore, the non-parametric Mann–Whitney U rank-sum test was used for the variance analysis between gender jumps. Analysis was performed with SPSS®️ Statistics Version 20 of IBM®️ software for Windows.

RESULTS
A total of 27 healthy adults (44.4% female, 55.6% male) signed informed consent to participate and complete the study. The anthropometric characteristics of the sample were: 24.29 ± 3.90 years (female – 22.91 ± 2.43 years, – male – 25.40 ± 4.48 years); 173.59 ± 9.74 height centimetres (female – 165.41 ± 5.60 cm, male 180.13 ± 7.01 cm); 72.57 ± 13.01 weight kilograms (female – 62.70 ± 8.24, kg, male – 80.47 ± 10.49 kg); 23.94 ± 2.95 BMI (female – 22.91 ± 2.79, male – 24.77 ± 2.84).

Table 1 shows the jump, kinetic and kinematic characteristics for all the sample (n=81 jumps) and significant differences of the jumps by gender. The highest difference between groups (gender) was in the dynamometry variables (p<0.001) and contact mat variables (p<0.001). Between the jumps test, the biggest difference between groups (gender) was in the CMJ jump test (p<0.001).

Table 2 shows the significant correlation between kinetic and kinematic variables of the study for all the sample, adjusted by sex, in the SJ test. The inertial sensor embedded in the smartphone demonstrated a correlation between the jump mat, SJ kinematic jump test variables and the dynamometry (see Table 2).

Table 3 shows the significant correlation between jump, kinetic and kinematic variables of the study for all the sample, adjusted by sex, in the CMJ test. The inertial sensor embedded in the smartphone demonstrated a correlation between the jump mat, CMJ kinematic jump test variables and the dynamometry (see Table 3).

Table 1. Jump Kinetic and kinematic characteristic and differences of the jumps by gender (n=81).

|                        | All Jumps (n=81) | Female Jumps (n=36) | Male Jump (n=45) | p Value |
|------------------------|------------------|---------------------|-----------------|---------|
| CMJ Inertial Sensor Variables |                  |                     |                 |         |
| Max Acceleration X SJ (m/s²) | 0.58 ± 0.45      | 0.46 ± 0.35         | 0.69 ± 0.49     | 0.037   |
| Min Acceleration X SJ (m/s²) | -0.55 ± 0.44     | -0.37 ± 0.21        | -0.69 ± 0.51    | 0.002   |
| Max Acceleration Z SJ (m/s²) | 0.84 ± 0.49      | 0.72 ± 0.45         | 0.94 ± 0.51     | 0.011   |
| Max Acceleration RV SJ (m/s²) | 2.20 ± 0.68      | 2.05 ± 0.51         | 2.32 ± 0.78     | 0.005   |
| SJ Inertial Sensor Variables |                  |                     |                 |         |
| Max Acceleration X CMJ (m/s²) | 0.82 ± 0.54      | 0.52 ± 0.28         | 1.06 ± 0.58     | 0.000   |
| Min Acceleration Y CMJ (m/s²) | -2.04 ± 0.64     | -1.77 ± 0.46        | -2.25 ± 0.70    | 0.001   |
| Max Acceleration Z CMJ (m/s²) | 1.05 ± 0.55      | 0.79 ± 0.48         | 1.25 ± 0.52     | 0.000   |
| Max Acceleration RV CMJ (m/s²) | 2.47 ± 0.63      | 2.17 ± 0.48         | 2.71 ± 0.64     | 0.000   |
| Contact Mat Variables |                  |                     |                 |         |
| Jump Height SJ (m) | 0.22 ± 0.08       | 0.17 ± 0.04         | 0.26 ± 0.07     | 0.000   |
| Jump Time SJ (s) | 0.42 ± 0.08       | 0.37 ± 0.05         | 0.46 ± 0.07     | 0.000   |
| Jump Height CMJ (m) | 0.33 ± 0.10       | 0.24 ± 0.04         | 0.40 ± 0.06     | 0.000   |
| Jump Time CMJ (s) | 0.51 ± 0.08       | 0.44 ± 0.04         | 0.57 ± 0.05     | 0.000   |
| Right dynamometry (N) | 251.93 ± 53.03    | 213.17 ± 21.44      | 282.93 ± 50.35  | 0.000   |
| Left dynamometry (N) | 234.96 ± 45.85    | 204.08 ± 21.13      | 259.67 ± 45.41  | 0.000   |
| Dynamometry Variables |                  |                     |                 |         |
| Mean ± SD |                     |                     |                 |         |
| Mean ± SD |                     |                     |                 |         |
| Mean ± SD |                     |                     |                 |         |

Table 2. SJ best correlations indexes.

|                      | Jump Height SJ – Right dynamometry | Jump Height SJ – Left dynamometry | Jump Height SJ – Max Acceleration ML SJ | Jump Height SJ – Min Acceleration ML SJ | Jump Time SJ – Right dynamometry | Jump Time SJ – Left dynamometry | Jump Time SJ – Max Acceleration ML SJ | Jump Time SJ – Min Acceleration ML SJ |
|----------------------|-----------------------------------|----------------------------------|----------------------------------------|----------------------------------------|--------------------------------|----------------------------------|--------------------------------.......|----------------------------------------|
|                      | p =0.312 (p=0.005)                | p =0.292 (p=0.008)                | p =0.301 (p=0.006)                      | p =0.257 (p=0.002)                      | p =0.337 (p=0.002)                  | p =0.309 (p=0.005)                 | p =0.285 (p=0.010)                    | p =0.234 (p=0.035)                    |

SD, Standard deviation; Max, maximum; Min, minimum; RV, resultant vector; X, x axis; Y, y axis; Z, z; CMJ, Countermovement Jump Test; SJ, Squat Jump Test; s, second; m, meters; N, Newton.
In general, the results obtained in this study show lower values in the female group. The most significant differences were found in the dynamometry and contact mat variables. It should be noted that analysing CMJ and SJ, the differences were more pronounced in the CMJ test. In the kinematics variables, in the x, z axis and the value in the resultant vector, the females obtained lower minimum and maximum accelerations in the SJ test than the male group. In the kinematics variables in the CMJ test, the females obtained lower minimum and maximum accelerations than the male group in the x, y, z axis and the value in the resultant vector. Males and females jumped higher in the CMJ than in the SJ (Table 3). It is well established that jumping could be enhanced by making compensation countermovements. The greater height jump score in the CMJ test could be explained by the active state initiated during the preparatory countermovement, whereas in the SJ, the countermovement is inevitably developed during the propulsion phase, so that the muscles can produce more force and work during shortening. The muscles’ elastic properties differ in structural composition between male and female, and these differences have a significant impact on the contribution to the force and power transference.

Other structural factors that have an influence on the localized differences are the pennation angle and the cross-sectional area. A greater pennation angle in the quadriceps muscle (vastus medialis) has an impact on the male and female jump test performance scores: males have significantly greater angles. In addition, the cross-sectional area plays an important role, in which males are able to activate more motor units resulting in greater force development, greater acceleration peaks and a high jump performance. With regards to the functionality, muscle function differences between male and female are found in the literature; for example, males have shown a superior aptitude in using the stretch-shortening cycle (active stretch in eccentric contraction of a muscle followed by an immediate shortening concentric contraction of that same muscle). In this active stretch, the storage of elastic energy is required, and this energy is used during the concentric action. This stretch load could be greater in males, and this has a direct impact on the kinematic and kinetic variables, which could explain the greater values registered in males with the smartphone inertial sensor in the SJ and CMJ tests in the present study. The higher male jump scores (kinematic and kinetic) compared to those of females suggest that they can be used to better characterize their jumping profile.

**CONCLUSION**

This study has described the anthropometric characteristics, dynamometry variables, contact mat variables (jump height and jump time) in the SJ and CMJ, as well as the kinematic variables from the inertial sensor in the CMJ and SJ jump tests. As predictors, it is important to observe the values of correlation between the kinetic variables with the performance in the jump tests (CMJ and SJ). The differences (active stretch energy load) could be explained by the differences identified in the present study between CMJ and SJ, being greater in CMJ for male than female.

All authors declare no potential conflict of interest related to this article.

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### Table 3. CMJ best correlation indexes.

| Variable 1                     | Variable 2                     | ρ       | p       |
|--------------------------------|--------------------------------|---------|---------|
| Jump Height CMJ – Right dynamometry | p 0.409 (p=0.000)            |         |         |
| Jump Height CMJ – Left dynamometry | p 0.392 (p=0.000)            |         |         |
| Jump Height CMJ – Max Acceleration ML CMJ | p 0.579 (p=0.000)            |         |         |
| Jump Height CMJ – Min Acceleration VT CMJ | p -0.338 (p=0.002)          |         |         |
| Jump Height CMJ – Max Acceleration AP CMJ | p 0.497 (p=0.000)            |         |         |
| Jump Height CMJ – Min Acceleration AP CMJ | p -0.300 (p=0.007)          |         |         |
| Jump Height CMJ – Max Acceleration RV CMJ | p 0.498 (p=0.000)            |         |         |
| Jump Time CMJ – Right dynamometry | p 0.436 (p=0.000)            |         |         |
| Jump Time CMJ – Left dynamometry | p 0.417 (p=0.000)            |         |         |
| Jump Time CMJ – Max Acceleration ML CMJ | p 0.561 (p=0.000)            |         |         |
| Jump Time CMJ – Min Acceleration VT CMJ | p -0.328 (p=0.003)          |         |         |
| Jump Time CMJ – Max Acceleration AP CMJ | p 0.487 (p=0.000)            |         |         |
| Jump Time CMJ – Max Acceleration RV CMJ | p 0.483 (p=0.000)            |         |         |

Max, maximum; Min, minimum; RV, resultant vector; X, x axis; Y, y axis; Z, z axis; CMJ, Countermovement Jump Test.
