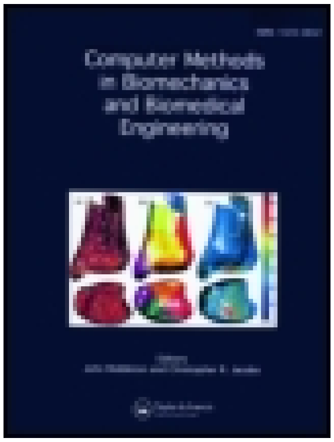

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KEYWORDS Perception; stability; pressure mapping; sports equipment; pilates

1. Introduction

Yoga, pilates and fitness activities involve poses or exercises that require a specific response from the body (Wang et al. 2013). In order to make the exercise easier or more pleasant, the mat has to provide, to some level, the following characteristics: grip (the mat must ensure the user will not slip during the practice), balance (the mat must ensure the balance of the user during the practice) and comfort (the mat must allow the user to practice without feeling the ground).

Biomechanical investigations are often conducted to assess grip, balance and comfort of sport or biomedical equipment. However, yoga and fitness mats have never benefited from this research. Therefore, the purpose of this study was to understand the interactions between the body and the mat, and to determine the most appropriate methods to assess a mat's mechanical aspects according to user's perception.

2. Methods

2.1. Participants

Fourteen healthy yogi participated in the study (2 males and 12 females, age: 36.0 ± 6.9 years old). The main practices of yoga were equally represented (Hatha, Ashtanga, Iyengar), and the experience ranged from 6 months to 20 years, with an average practicing time of 2.8 ± 1.7 h per week. No injuries to the lower extremity were sustained over the previous 6 months.

2.2. Biomechanical study design

The biomechanical study was divided in three tests according to the three criteria. Each criterion was represented by a posture or exercise and required different measurement methods.

Grip was assessed with the downward-facing dog pose (Figure 1), repeated three times with identical starting position. Mats were fixed on a forceplate (Kistler, Switzerland) set at a sampling frequency of 200 Hz. Participants' hands were placed over the forceplate to measure the relative shear (F_S) and vertical (F_V) forces and calculate the coefficient of friction ($COF = F_S/F_N$) as described by Blau (2001).

On the same forceplate, the posture of the tree was repeated five times during 20s to evaluate balance. Centre of pressure (COP) data were calculated for each trial for mediolateral and anteroposterior axis: deviation, range of motion, velocity (Raymakers et al. 2005).

Finally, a gym posture, with the knees on a pressure mapping system (Xsensor Technology Corp., Canada) held for 60s, was performed for the evaluation of comfort. The system enables the analysis of peak and mean pressure, and contact area, which have been linked to comfort perception (Gyi & Porter 1999).

After each series of postures, the participants were asked to answer questions about their perception of the mat on scales ranging from 1 (no grip, balance or comfort) to 9 (extreme grip, balance or comfort).

A total of 12 conditions were tested: 6 yoga mats, 2 pilates mats, 3 gym mats and 1 condition on the ground. The differences between the mats are foam materials (for example, PVC, TPE, rubber), density, thickness (ranging from 3 to 15 mm) and surface characteristics (smooth or embossed design). Both mats and criteria orders were randomized between the participants.

2.3. Mechanical tests

A series of mechanical tests were performed on the mats, including compression (inspired of international standard ISO 3386/1), resilience (ISO 8307:2007), soft touch (consists of a compression cycle with an indentor), grip (ASTM D 18994:2011-1) and density.

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Figure 1. From left to right, the downward-facing dog, the tree and the gym poses.

2.4. Statistical analysis

Single- and multiple-linear regressions were used to evaluate the relationship between sensory data and biomechanical or mechanical parameters. This allowed the development of predictive models to estimate a perception based on mechanical tests. The significant threshold was set at $p < 0.05$.

3. Results and discussion

The coefficient of friction measured in the downward-facing dog pose produced a mean value of 0.49 across the conditions, with a standard error of the mean (SEM) ranging from 0.03 to 0.048. It showed a significant but low correlation with the perception of grip ($p < 0.05$, $R^2 = 0.48$). On the other hand, the perception of grip strongly correlated with grip mechanical measurements: static coefficient of friction and loading rate between 2 and 5 N. A predictive model of perceived grip can be determined with multiple-linear regression ($p < 0.001$, $R^2 = 0.91$).

The biomechanical method proved not to be relevant to describe the feeling of grip. The posture may not have been appropriate as we observed different techniques from the participants and strong inter- and intra-subjects variability. Plus, friction was measured only under the hands, whereas the participants also had their feet in contact with the mat.

Balance analysis showed that only the deviation and the range of motion of the COP on the anteroposterior axis are relevant. The range of motion averages at 0.037 m (SEM: 0.0015–0.0027) and presents the best correlation coefficient with the perceived balance ($p < 0.001$, $R^2 = 0.93$). This parameter is also strongly linked to the soft touch test results, particularly with the time needed to reach 50 N, and the density of the component. A predictive model of perceived balance is established based on these two parameters ($p < 0.001$, $R^2 = 0.98$).

Biomechanical and sensory data were also highly linked to the mats thickness, although it does not lead to a predictive model as strong as the previous one. We think that this is because thickness cannot describe the component behaviours as well as the soft touch test. Furthermore, all material were foams, with very similar characteristics but very different thicknesses.

Among the parameters extracted from the pressure mapping system for the assessment of comfort, the contact area is the most discriminating data. The mean value is 75.9 cm^2 (SEM: 4.8–7.6). It is the most correlated with sensory data, negatively ($p < 0.00$, $R^2 = 0.82$).

The compression test might have been expected to be the most related to comfort, as it is often used to describe the softness of a foam component. However, while some correlations were significant, it did not present coefficients of determination higher than 0.68. The soft touch test produces R^2 values of 0.98 and 0.83 when related to measured contact area and perceived comfort, respectively. The geometry of the soft touch test is closer to the geometry of a knee on a mat, as the surface of the indentor is smaller than that of the sample. However, the best predictive model for perceived comfort accounts for the two tests ($p < 0.001$, $R^2 = 0.92$), using the indentation time of the soft test, and the energy loss of the compression test.

We note that perceived balance and comfort both use the same test result (time from the soft touch test) with opposite coefficients. According to these models, a comfortable mat will provide poor balance.

4. Conclusions

The study brought new information on the measurable factors that can describe grip, balance and comfort perception of yoga and gym mats. Strong correlations exist between reliable biomechanical measurements, mechanical tests and perception, allowing developing predictive models. These will help evaluating the characteristics of mats in order to provide more relevant products to yogis and gym users.

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