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Influence of dental occlusion conditions on plantar pressure distribution during standing and walking – A gender perspective

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ABSTRACT

The aim of this study was to investigate gender-specific influences of different symmetric and asymmetric occlusion conditions on postural control during standing and walking.

The study involved 59 healthy adult volunteers (41 f/19 m) aged between 22 and 53 years (30.2 ± 6.3 years). Postural control measurements were carried out using a pressure plate by measuring plantar pressure distribution during standing and walking test conditions. Seven different occlusion conditions were tested. Prior to a MANOVA model analysis, the relationship between the two test conditions were checked using a factor analysis with a varying number of factors (between 2 and 10).

The plantar pressure distributions during walking and standing are independent test conditions. The coefficient of variance across all variables between the conditions and genders was not significant: $t(46) = 1.51$ ($p = 0.13$). No statement can be made whether, or not, the influence of gender is greater than the influence of the conditions.

Healthy male and female test subjects did not show any difference between seven occlusion conditions on the plantar pressure distribution while standing or walking. No differences between the genders were found for any of the investigated variables. In contrast to custom-made occlusion splints, simple cotton rolls appear not to influence the neuromuscular system in a systematic manner.

1. Introduction

Postural control is defined as the act of maintaining, achieving or restoring a state of balance during any posture or activity. Pathologies, such as chronic and acute low back pain, do influence postural control. Measuring the plantar pressure distribution during standing and walking can provide some information about postural control. There is already some evidence available [1] that people with low back pain have altered plantar pressure distributions. Therefore, a clear understanding of the pressure distribution during standing and walking may help in detecting pathologies [2].

Standing and walking are the two fundamental movements performed in everyday life. During standing, both feet should be equally loaded [3], however, the plantar pressure distribution ratio during standing, between the forefoot and rear foot, is around 4:6 when the feet are parallel to each other [3–5]. The neuromuscular system adjusts, constantly, the body posture in order to keep balance. During normal, neutral standing, the medio-lateral movement is restricted in the ankle, knee and hip joints. The alignment is much better for the anterior-posterior rotation axes, therefore, the flexion and extension in the ankle, knee and hip joints can be easily performed. This higher freedom of movement in the anterior-posterior direction has been confirmed in many studies [6–9]; for instance, for young adults < 30 years, the mean body sway in the anterior-posterior direction is around 19 mm, while the mean sway in the medio-lateral direction is between 7 and 9 mm [6–9]. The control of body balance is also age-dependent. For test subjects above 60 years, an increase of about 50% in both directions has been observed; this may be due to a loss of vestibular sensory organs, especially caused by hair cell

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degeneration [10]. Overall, the plantar pressure distribution during standing and walking serves as a window to postural control.

The literature on the influence of occlusion conditions on pressure distribution, as well as on postural control, however, is controversial [8,11–15]. Furthermore, occlusion splints can influence the kinematics [16] and kinetics [17,18] of people. Changes in the temporomandibular joint (TMJ) can have an immediate effect on muscle activity for body posture, body stability and physical performance [19–22]. Currently, there are many theories which attempt to explain these observations; some of the most prominent theories are muscle chain theory, activation or deactivation of the trigeminal nerve and subsequent interaction in the brain stem and fascia chain theory [23–30]. The current observations show that the influence of an occlusion change can have both immediate effects (observed after a view seconds) [16,31] and long-term effects (12 weeks) [32].

In addition to the controversial influence of occlusion changes on the plantar pressure distribution during standing and walking, gender-specific differences in standing and walking are also contentious in the literature. In general, gender influences a variety of biological functions, for example, differences in pain threshold, hormone balance, connective tissue and muscularity [33-36]. Furthermore, Maurer and Nigg [37,38] reported different walking patterns which may be due to different anatomy and body composition between the genders. However, Cuz-Gomez et al. [39] found no differences between gender for the postural stability while standing on different surfaces with either open or closed eyes. On the other hand, Farenc et al. [36] showed that men have a larger sway amplitude for horizontal displacements of the center of gravity than women. This observation can be explained by both morphological and physiological (architectural properties of the soleus muscle) characteristics [36,40] and, furthermore, has also been observed in older people, where men have a lower level of postural stability compared with women [41]. In addition, Bussey et al. [42] showed that women appear to have a stronger effect of limb dominance on their anticipatory postural control strategy for rapid single leg lift.

While walking, male test subjects have been reported as having a larger deviating center of pressure (COP) progression angle during the forefoot contact phase, foot flat phase and forefoot push-off phase than female test subjects [43]. In addition, the peak pressure and peak force in the medial toe and forefoot are greater for men while the contact area in the central forefoot and heel area are also larger for men than women. Females, on the other hand, have a greater contact area in the midfoot than men; this may be due to the larger foot size of men compared to women [44]. Furthermore, for men, an increase of the mean pressure on the lateral forefoot and a decrease of the longitudinal arch of the foot with aging has been observed, whilst women show an increase of the mean pressure in the medial ball foot with age. These results have also been confirmed within a systematic review, including a meta-regression analysis, by Telfer and Bigham [45].

Gender-specific differences also exist for the temporomandibular system (TMS); for instance, temporomandibular disorders (TMD) are found more frequently in females than males [46–48]. Bite force also differs between the genders [49,50]; this is highest for severe brachyfacial male individuals being heavy and tall, as well as being between 41 and 50 years old. On the other hand, the prevalence of dental attrition is not associated with factors of age, gender, occlusion and the temporomandibular joint (TMJ) symptomatology [51]. Furthermore, the sagittal condylar inclination is not gender specific [52]. There is some evidence that the force-controlled bite, the jaw positions and the occurrence of TMD influence postural control [53–55]. However, the role of gender on the influence of the occlusion condition on postural control is unclear [3–9,12].

Since the occlusion influence on the plantar pressure distribution in standing and walking on the same volunteer collective has not, as yet, been analyzed, this is the primary aim of the present study. As both standing and walking are equally important in everyday life, both movements were measured. Furthermore, a series of different occlusion conditions, symmetric as well as asymmetric, were undertaken. Currently, gender-specific differences of occlusion conditions are not well represented in the scientific literature of this research field. With the potential influence of occlusion conditions on postural control, the second aim of this study is to investigate gender-specific influences of occlusion conditions on postural control. This should yield a comprehensive picture of possible gender-specific differences.

Therefore, the following hypotheses were tested:

1 The plantar pressure distributions of standing and walking are independent of each other.
2 During standing, men have a larger body sway in the frontal and sagittal displacements than women.
3 While walking, men have a higher maximal plantar pressure distribution in the forefoot area than women.
4 There is a gender-specific difference between the occlusion conditions on the plantar pressure distribution for both the standing and walking test conditions.

2. Material and methods

2.1. Test subjects

The study involved 59 healthy adult volunteers (41 female (66%), 19 male (34%)) with an age of 30.2 ± 6.3 years (ranging between 22 and 53 years). Inclusion criteria were a complete dentition and no dental pathologies or dysfunction of the occlusion. On self-report, the volunteers stated that they had not been suffering from peripheral, central vestibular nor somatosensory dysfunction. Furthermore, the test subjects did not suffer acute or chronic pathologies of the muscular skeletal system.

Exclusion criteria comprised: current orthodontic treatment, therapy with occlusion appliance, cracking or rubbing sounds in the TMJ, pain during TMJ movements or chewing malformations in the jaw area (such as cleft lip and palate), traumata or operations on the upper or lower jaw, jaw clamp or jaw lock, tumours of the oral and maxillofacial region, acute infection and medication with muscle relaxants.

A positive ethics recommendation from the Department of Medicine of the Goethe University Frankfurt am Main (ethic-number: 92/11) was obtained. Its guidelines relate to the ethical principles of medical research in humans which are set out in the current version of the 2008 Helsinki Declaration.

2.2. Measurement device

A plantar pressure plate GP multisens (® GeBioM, Münster, Germany) was used for measuring the plantar pressure distribution while standing and walking. This has dimensions of 550 × 455 × 4 mm^3. The active area is 390 × 390 mm^2 and consists of 48 × 48 sensors, resulting in a total number of 2304 resistive pressure sensors, thus, the spatial resolution is 1.5 sensors/cm^2. The temporal resolution for this study was 4 ms as the sampling rate was 250 Hz. The measuring error for the plate is ± 5% according to the manufacturer.

2.3. Occlusion conditions

Seven different occlusion conditions were tested: the **neutral** condition [56], where test subjects took their habitual bite position, the **maximum** intercuspation**,** in which the cusps of the teeth

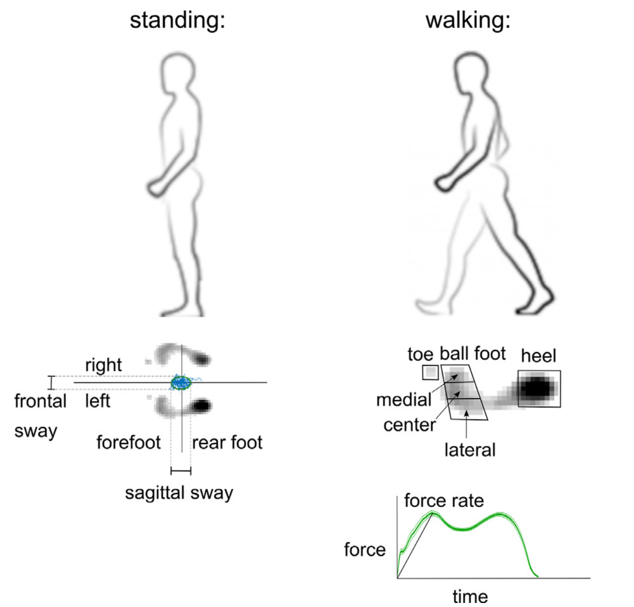

Fig. 1. Explanation of the measured variables. For the standing test condition, the measured variables were the sway in the frontal plane and the sway in the sagittal plane. The pressure area was divided into four quadrants: forefoot right, forefoot left, rear foot right, rear foot left. In addition the total pressure of the rear foot and the total pressure of the right foot; only the rear and right were used because the relative pressures were used and, therefore, the forefoot and the left contribute the remaining to 100%. For the walking test condition, the pressure of the toe, ball foot (lateral, center, medial) and the heel were used. In addition, the force rate, the ratio between the braking and acceleration force and the contact time were used. All measured variables were measured for the left and right sides.

of both arches fully interpose themselves, four other occlusion conditions, adjusted by using a cotton roll (right and left [**symmetric**] side in the premolar region, only **right** or **left** in the premolar region or **front** blocking) and one silicon panel (Bausch KG; Cologne, Germany) placed in the **front (front silica)**.

2.4. Measurements

In total, 24 variables were tested. Eight variables were measured within the standing test condition and 16 variables were measured within the walking test condition. The specific variables measured were the following:

Standing test condition: Test subjects stood barefoot for 30 s in a habitual position (Fig. 1). The measured variables included the maximal sway amplitude in the frontal and sagittal directions [mm], the relative pressure distribution of all four quadrants consisting of the **left and right (fore and rear) foot** [%] and the relative pressure distribution of the right foot [%] (**right foot**) and forefoot [%] (**forefoot**). The left foot and rear foot were excluded as they are the inverse of the right foot and the forefoot, respectively.

Walking test condition: Test subjects walked barefoot with constant speed over the pressure plate and hit the pressure plate with only one foot (Fig. 1). The measured variables included the maximum pressure during the roll-off for **toe, mid foot (medial, mid and lateral area)** and **heel area** (**left and right foot**) [N/cm^2], **force rate** during foot contact (right/left foot) [BW/s], ratio of **brake force to the acceleration force** [%] (**left** and **right**) and the **contact time** of both feet [s].

All pressure data were normalized by the maximal pressure, therefore, the pressure data were independent of the body weight of the test subjects and so comparisons between the genders could be performed.

2.5. Measurement protocol

Detailed instructions were provided and the procedures for the standing and walking test conditions were demonstrated. The standing trial was performed first, followed by the walking trial. While walking, the right leg was first tested followed by the left leg in additional trials. The measurement was repeated three times before the next condition was performed.

The occlusion conditions were performed in a randomized order.

2.6. Statistics

Due to the seven different occlusion conditions, 24 variables and gender, we had to control for several influencing factors, thus, we used a MANOVA model in order to account for multi comparisons. The mutual independence of the variables was checked with a correlation analysis. The cut-on for dependence was set to $r = 0.75$. Prior to the MANOVA, the relationship between the two measurement systems was checked. This was executed using a factor analysis with a varying number of factors (between 2 and 10).

The normal distribution of all mutually independent variables was checked (Lilifort test). However, as the variables were not normally distributed, data distribution transformation was performed and the rank of the data calculated. An inverse normal distribution was performed on the rank of the data resulting in a normal distribution of the data. MANOVA was set up with 168 within factors and 2 between factors. The within factors comprised the seven occlusion conditions and the 24 variables of the pressure distribution during standing and walking; the between factors comprised the gender and the age of the test subjects. The MANOVA model was set to test within the 168 columns of conditions x variables between the two factors of gender and age and the interaction of gender and age (gender + age + gender:age). For the variables, the test of equal mean was performed for the seven conditions, for the 24 variables and within each individual group of condition + variable + condition:variable. For all tests, a separate mean was used.

Significant comparisons within the MANOVA would have been subjected to an ANOVA.

In addition, to compare the influence of occlusion conditions with gender, the coefficient of variance was calculated and compared through all variables. The significance level was set to 0.05. All statistical analysis was carried out with Matlab® (mathworks, Version 2018a).

3. Results

Factor analysis revealed that the two measurement conditions, standing and walking, have different dimensions (Fig. 2). Therefore, these two measurement conditions can be considered as independent measurement conditions. The best separation was achieved with three factors; the first and the third factors loaded mainly on standing trials, while the second factor loaded mainly on walking trials. The 1st factor can be seen as the anterior-posterior factor, the 3rd factor as the symmetry between left and right and the 2nd factor describes the mean pressure pattern during walking.

The explained variance of the three factors was 16%, 14% and 8% for the 1st, 2nd and 3rd factors, respectively. Gender specific differences were found for the 1st factor, but not for the 2nd and 3rd. Male test subjects showed a mean coefficient of −0.35(0.9), while female test subjects showed a mean coefficient of 0.16(1.0) on the 1st factor (mean (standard deviation)). The difference between the two means was $t(411) = 24.78$ ($p<0.001$). A gender-specific factor analysis revealed that the result for the female group matches the overall results reasonably well. The correlation between the female loadings and the overall loadings was $|r| = 0.95(0.037)$. For

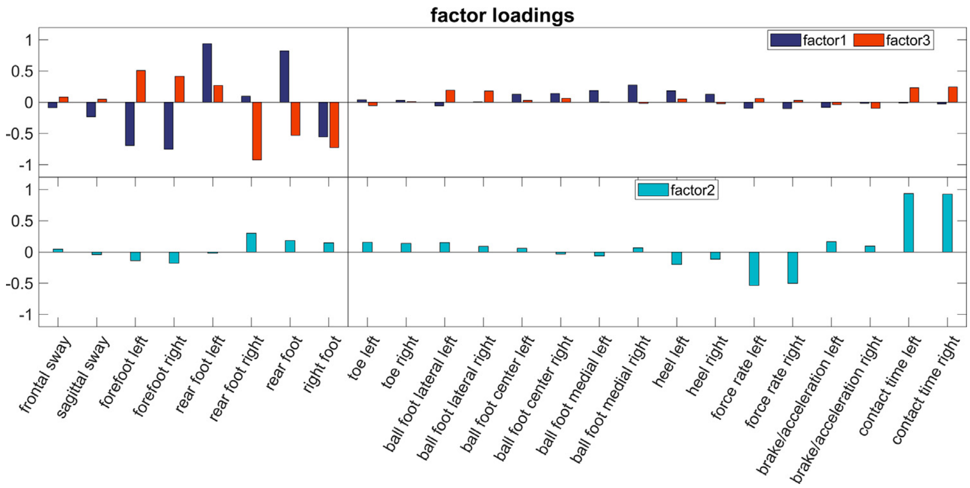

Fig. 2. Factor loadings for the 24 variables. The two measurement conditions are clearly separate and are, therefore, two independent measurement conditions.

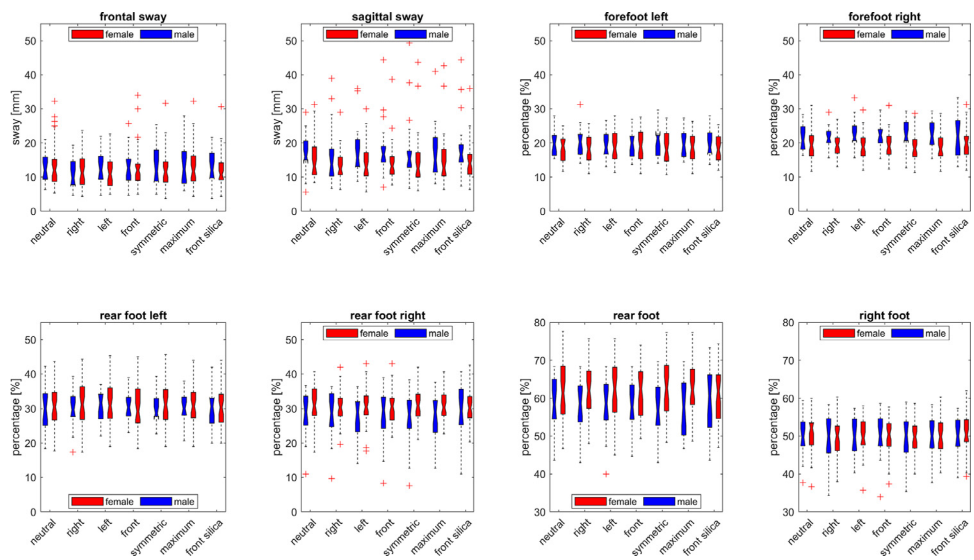

Fig. 3. Pressure and postural sway during the standing test condition. The measured variables have been plotted for the seven conditions, separated into the two gender groups. Note that the input into the MANOVA was not the raw data, but the rank transformed data.

male subjects, the 1st and 2nd factor switched ranking. The absolute value for the correlation with the corresponding factors was |r| = 0.66(0.32), where the 2nd factor of the male subgroup loaded the worst on the 1st factor of the overall group, $r = 0.29$. The correlation between the 2nd factor of the male subgroup and the 1st factor of the overall group was $r = -0.9$ and the correlation between the 3rd factor of the male subgroup and the 3rd factor of the overall group was $r = -0.77$.

The pressure and sway measurements are presented in Fig. 3. The measured data were separated into the seven occlusion conditions and the two gender groups. The data for the walking trial are presented in Fig. 4. Once more, the data were separated into the seven occlusion conditions and the two gender groups. Visual inspection does not show a clear difference between the seven occlusion conditions which was confirmed when the MANOVA model was applied to the data.

The MANOVA results revealed no difference within conditions and variables, nor between gender and age (Table 1). Therefore, no further post-hoc tests were carried out.

The coefficient of variance across all variables between the conditions and gender was not significant: t(46) = 1.51 (p = 0.13). The differences between the two genders are, therefore, greater than between the occlusion conditions, but without a significant p-value.

4. Discussion

The first aim of this investigation was to determine the influence of different occlusion conditions on pressure measurements during standing and walking. The second aim was to investigate the relationship between the two genders on these variables. Factor analysis showed that the measurement of the pressure distribution during walking and standing are independent of each other. There is no direct correlation between variables of the pressure distribution during standing and the variables of pressure distribution during walking. Therefore, both measurements add different aspects to the pressure distribution while using the occlusion conditions used in this study. Within this study, the 1st hypothesis was confirmed; the overall statement of the 1st hypothesis is true for both genders. The 1st and the 3rd factors loaded mainly on the standing measurement. The 2nd factor loaded mainly on the walking measurement. With a summed explained variance of 24%, the 1st and 3rd factors explained much more of the variance than the 2nd factor with 14% which means that the standing test

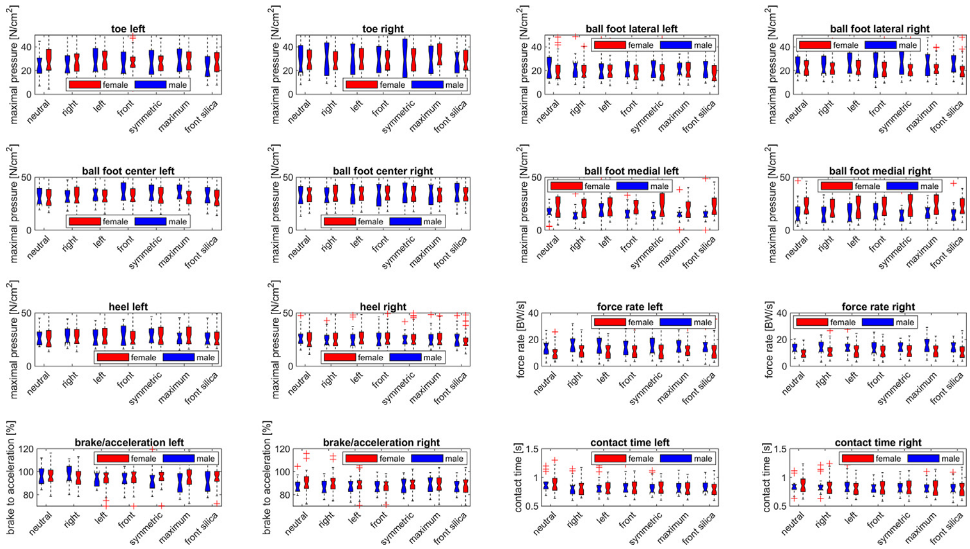

Fig. 4. Pressure, force and contact time of the walking test condition. The measured variables have been plotted for the seven conditions, separated into the two gender groups. Note that the input into the MANOVA was not the raw data, but the rank transformed data.

Table 1
MANOVA Table. Statistical analysis was performed in one comprehensive step, controlling for multi comparisons. No significance was found in relevant variables.

Within	Between	Statistic	Value	F	R Square	df1	df2	P Value
(Intercept)	(Intercept)	Wilks	0.81	13.13	0.19	1	55	**0.001**
(Intercept)	Gender	Wilks	1.00	0.04	0.00	1	55	0.852
(Intercept)	Age	Wilks	1.00	0.05	0.00	1	55	0.829
(Intercept)	gender:age	Wilks	1.00	0.00	0.00	1	55	0.968
condition	(Intercept)	Wilks	0.80	14.14	0.20	1	55	**0.000**
condition	Gender	Wilks	1.00	0.10	0.00	1	55	0.759
condition	age	Wilks	1.00	0.08	0.00	1	55	0.780
condition	gender:age	Wilks	1.00	0.02	0.00	1	55	0.879
variable	(Intercept)	Wilks	0.86	9.07	0.14	1	55	**0.004**
variable	gender	Wilks	1.00	0.09	0.00	1	55	0.763
variable	age	Wilks	1.00	0.10	0.00	1	55	0.756
variable	gender:age	Wilks	1.00	0.02	0.00	1	55	0.880
condition:variable	(Intercept)	Wilks	0.85	9.53	0.15	1	55	**0.003**
condition:variable	gender	Wilks	1.00	0.17	0.00	1	55	0.681
condition:variable	age	Wilks	1.00	0.13	0.00	1	55	0.717
condition:variable	gender:age	Wilks	1.00	0.07	0.00	1	55	0.795

condition explained 20% more of the overall variance. The walking test condition is more complex and has a higher degree of freedom, thus, different subjects experience different pressure distributions. In total, this higher spread of different solutions may lead to the reduced loading on several factors for the walking test condition.

A MANOVA including all contributing variables, as well as the confounding factor age, was performed. No significance was found in between the occlusion conditions, within the variables nor between genders, therefore, the 2nd, 3rd and 4th hypotheses have to be rejected. Within this study, women showed no differences in the pressure distribution between the investigated occlusion conditions; this is true for all occlusion conditions for the investigated variables.

The factor analysis evaluates the relationship between the two measurement test conditions; the resulting factors combine the correlated variables. Within this study, the results show that the forefoot (left and right) and rear foot (left and right) contributed the most to the 1st factor (Fig. 2). The forefoot variables point in the opposite direction to the rear foot variables, meaning that this factor demonstrates the amount of forward leaning. The higher the coefficient for this factor, the higher the pressure under the rear part of the foot and, therefore, the less is the resulting forward lean. The 3rd overall factor describes the differences between the left and the rightfoot (Fig. 2); these were especially evident with the loading points in the opposite directions for the left rear foot and the right rear foot. Furthermore, the loading is high for the side variable right foot but low for the anterior posterior variable rear foot. This suggests that this factor explains the shift of the body weight from the left to the right side during standing and not so much the shift from the body forwards to backwards. A high loading on this factor means a shift to the right side, while a negative loading means a shift to the left side. The 2nd factor load reveals that there is scarcely any difference between the left and the right walking trial (see Fig. 2).

At first sight, this seems to contradict earlier investigations [53–55]. However, on closer observation, this reveals that the main difference between the presented study and other studies are the specific occlusion conditions. There is some evidence that the TMJ has to be placed in the correct position; a pure activation of the facial muscle through a cotton roll or through an over-the-counter splint [57–59] is not sufficient. Differences with respect to the occlusion condition have been shown when the TMJ was placed in a neutral condition. It has been speculated that an activation of the facial muscle affects the activation of other muscles via the motor cortex; this theory is known as the concurrent activation potentiation [60]. Within the current study we have shown that the mechanism affecting distal muscles through an activation of the TMJ is, at least, more complex.

In terms of gender-specific reactions due to the dental occlusion conditions, our factor loadings show that the female test subjects and male test subjects have a small difference within the factor loadings. While the female test subjects' results follow very closely the overall results, the male test subjects have different loadings for the 1st and 2nd factor (additional analysis on the data is not shown as the data were not significant). In fact, the two factors switched with each other, showing that for male test subjects, the walking trials explain more of the variance within the data set than for female test subjects. This would suggest that there is a difference in the two genders with respect to the pressure data of standing and walking. Male test subjects have higher-pressure values during walking, while female test subjects shift their weight more over the heel (Figs. 3 and 4), however, none of these results were significant. The projection of the data onto the overall 1st factor pointed in the same direction as the gender-specific factor loadings. The male test subjects showed a mean projection of −0.35(0.9) on the 1st overall factor, while the female test subjects showed a mean projection of 0.16(1.0). The difference between these two groups is significant. Therefore, it may be speculated that, overall, female test subjects stand slightly more to the back, while male test subjects stand with a slightly more forward lean (Fig. 3). Standing more to the back can be achieved with a non-muscular stance. A possible explanation could be that female subjects prefer the non-muscular stance because they have less muscular mass [36]. Since body sway in the upright position is mainly controlled by short activations of the soleus and gastrocnemius muscles of the calf, the soleus muscle, especially, acts as an antigravity muscle [40]. Here, structural differences of the soleus muscle (e.g., muscle thickness, length of muscle fibers) are decisive for body sway (especially in the sagittal direction) [36]. Although the soleus muscle is thicker and its muscle fibers are shorter in men than in women, these physiological differences do not lead to different body fluctuations within the genders.

Interestingly, even the asymmetric occlusion conditions did not appear in the results. This would mean, again, that the effects of an unspecific treatment cancel out each other. This may be because some test subjects would need an asymmetric change on the left side, others an asymmetric treatment on the right side and a third group would benefit from a symmetric treatment. In summary, this again supports the notion that only an individually-adjusted occlusion situation or a splint condition has an overall effect on the pressure distribution and, therefore, on postural control.

Unfortunately, more female than male subjects were included in this study. This may have led to a bias in the results as the probability is then shifted too much in favor of the alternative hypotheses. The study itself deals with the normal challenge of many biomechanical studies, where many measurements have to be performed in order to draw the best general picture. This, again, may lead to a too conservative interpretation of the results. However, as this work also investigates the relationship between standing and walking, it does provide a first insight into combining these two results. In future research, the results presented in this article can be used choosing a better selection of the variables in advance.

5. Conclusion

Healthy male and female test subjects did not show any differences between the seven occlusion conditions on the pressure distribution while standing and walking. Within this study, no difference was found overall, nor within the gender subgroups. In addition, no differences between genders were found for any of the investigated variables. In contrast to custom-made occlusion splints, simple cotton rolls do not influence the neuromuscular system in a systematic manner.

Declaration of Competing Interest

None.

Funding

None.

Ethical Approval

A positive ethics recommendation from the Department of Medicine of the Goethe University Frankfurt am Main (ethic-number: 92/11) was obtained.

References

[1] Knox MF, Chipchase LS, Schabrun SM, Romero RJ, Marshall PWM. Anticipatory and compensatory postural adjustments in people with low back pain: a systematic review and meta-analysis. The Spine J: Off J North Am Spine Soc 2018;18(10):1934–49 Epub 2018/06/16PubMed PMID: 29906616. doi:10.1016/j.spinee.2018.06.008.

[2] Buldt AK, Murley GS, Butterworth P, Levinger P, Menz HB, Landorf KB. The relationship between foot posture and lower limb kinematics during walking: a systematic review. Gait Posture 2013;38(3):363–72. doi:10.1016/j.gaitpost.2013.01.010.

[3] Syed N, Karvannan H, Maiya AG, Binukumar B, Prem V, Chakravarty RD. Plantar pressure distribution among asymptomatic individuals: a cross-sectional study. Foot Ankle Spec 2012;5(2):102–6 Epub 2012/02/22PubMed PMID: 22343819. doi:10.1177/1938640011434503.

[4] Cavanagh PR, Rodgers MM, Liboshi A. Pressure distribution under symptom-free feet during barefoot standing. Foot Ankle 1987;7(5):262–76 Epub 1987/04/01PubMed PMID: 3583160.

[5] Pomarino D, Pomarino A. Plantar Static Pressure Distribution in Healthy Individuals: percentiles for the Evaluation of Forefoot Loading. Foot Ankle Spec 2014;7(4):293–7 Epub 2014/04/24PubMed PMID: 24756116. doi:10.1177/1938640014528973.

[6] Degani AM, Leonard CT, Danna-Dos-Santos A. The effects of early stages of aging on postural sway: a multiple domain balance assessment using a force platform. J Biomech 2017;64:8–15 Epub 2017/09/13PubMed PMID: 28893391. doi:10.1016/j.jbiomech.2017.08.029.

[7] Qiu F, Cole MH, Davids KW, Hennig EM, Silburn PA, Netscher H, et al. Enhanced somatosensory information decreases postural sway in older people. Gait Posture 2012;35(4):630–5 Epub 2012/01/17PubMed PMID: 22245163. doi:10.1016/j.gaitpost.2011.12.013.

[8] Scharnweber B, Adjami F, Schuster G, Kopp S, Natrup J, Erbe C, et al. Influence of dental occlusion on postural control and plantar pressure distribution. Cranio: J Craniomandibular Pract 2017;35(6):358–66 Epub 2016/10/21PubMed PMID: 27760494. doi:10.1080/08869634.2016.1244971.

[9] Bonnet CT, Cherraf S, Szaffarczyk S, Rougier PR. The contribution of body weight distribution and center of pressure location in the control of mediolateral stance. J Biomech 2014;47(7):1603–8 Epub 2014/04/01PubMed PMID: 24679709. doi:10.1016/j.jbiomech.2014.03.005.

[10] Rauch SD, Velazquez-Villasenor L, Dimitri PS, Merchant SN. Decreasing hair cell counts in aging humans. Ann. N. Y. Acad. Sci. 2001;942:220–7 Epub 2001/11/17PubMed PMID: 11710464.

[11] Cuccia AM. Interrelationships between dental occlusion and plantar arch. J Bodyw Mov Ther 2011;15(2):242–50 Epub 2011/03/23PubMed PMID: 21419367. doi:10.1016/j.jbmt.2010.10.007.

[12] Ferrario VF, Sforza C, Schmitz JH, Taroni A. Occlusion and center of foot pressure variation: is there a relationship? J Prosthet Dent 1996;76(3):302–8 Epub 1996/09/01PubMed PMID: 8887805.

[13] Perinetti G, Contardo L, Silvestrini-Biavati A, Perdoni L, Castaldo A. Dental malocclusion and body posture in young subjects: a multiple regression study. Clinics (Sao Paulo) 2010;65(7):689–95 Epub 2010/07/30PubMed PMID: 20668626PubMed Central PMCIDPMCPMC2910857. doi:10.1590/s1807-59322010000700007.

[14] Tardieu C, Dumitrescu M, Giraudeau A, Blanc J-L, Cheynet F, Borel L. Dental occlusion and postural control in adults. Neurosci. Lett. 2009;450(2):221–4. doi:10.1016/j.neulet.2008.12.005.

[15] Julia-Sanchez S, Alvarez-Herms J, Gatterer H, Burtscher M, Pages T, Viscor G. Dental Occlusion Influences the Standing Balance on an Unstable Platform. Motor Control 2015;19(4):341–54 Epub 2015/02/13. doi: 10.1123/mc.2014-0018. PubMed PMID: 25674772.

[16] Maurer C, Stief F, Jonas A, Kovac A, Groneberg DA, Meurer A, et al. Influence of the lower jaw position on the running pattern. PLoS ONE 2015;10(8):e0135712 Epub 2015/08/14PubMed PMID: 26270961PubMed Central PMCIDPMCPMC4535904. doi:10.1371/journal.pone.0135712.

[17] Maurer C, Heller S, Sure JJ, Fuchs D, Mickel C, Wanke EM, et al. Strength improvements through occlusal splints? The effects of different lower jaw positions on maximal isometric force production and performance in different jumping types. PLoS ONE 2018;13(2):e0193540 Epub 2018/02/24PubMed PMID: 29474465; PubMed Central PMCID: PMCPMC5825140. doi:10.1371/journal.pone.0193540.

[18] Dias A, Redinha L, Vaz JR, Cordeiro N, Silva L, Pezarat-Correia P. Effects of occlusal splints on shoulder strength and activation. Ann. Med. 2019:1–22 Epub 2019/01/11PubMed PMID: 30628462. doi:10.1080/07853890.2019.1566766.

[19] Moon HJ, Lee YK. The relationship between dental occlusion/temporomandibular joint status and general body health: part 1. Dental occlusion and TMJ status exert an influence on general body health. J Alternat Complement Med (New York, NY) 2011;17(11):995–1000 Epub 2011/11/11PubMed PMID: 22070442. doi:10.1089/acm.2010.0739.

[20] Yurchenko M, Hubalkova H, Klepacek I, Machon V, Mazanek J. The neuromuscular approach towards interdisciplinary cooperation in medicine. Int Dent J 2014;64(1):12–19 Epub 2014/01/28PubMed PMID: 24460590. doi:10.1111/idj.12057.

[21] Ohlendorf D, Seebach K, Hoerzer S, Nigg S, Kopp S. The effects of a temporarily manipulated dental occlusion on the position of the spine: a comparison during standing and walking. The Spine J: Off J North Am Spine Soc 2014;14(10):2384–91 Epub 2014/02/04PubMed PMID: 24486478. doi:10.1016/j.spinee.2014.01.045.

[22] Manfredini D, Castroflorio T, Perinetti G, Guarda-Nardini L. Dental occlusion, body posture and temporomandibular disorders: where we are now and where we are heading for. J Oral Rehabil 2012;39(6):463–71 Epub 2012/03/23PubMed PMID: 22435603. doi:10.1111/j.1365-2842.2012.02291.x.

[23] Manni E, Palmieri G, Marini R, Pettorossi VE. Trigeminal influences on extensor muscles of the neck. Exp. Neurol. 1975;47(2):330–42. doi:10.1016/0014-4886(75)90261-7.

[24] Tramonti Fantozzi MP, Diciotti S, Tessa C, Castagna B, Chiesa D, Barresi M, et al. Unbalanced occlusion modifies the pattern of brain activity during execution of a finger to thumb motor task. Front Neurosci 2019;13:499 Epub 2019/06/04PubMed PMID: 31156377; PubMed Central PMCID: PMCPMC6533560. doi:10.3389/fnins.2019.00499.

[25] Perinetti G, Contardo L. Posturography as a diagnostic aid in dentistry: a systematic review. J Oral Rehabil 2009;36(12):922–36 Epub 2009/11/03PubMed PMID: 19878440. doi:10.1111/j.1365-2842.2009.02019.x.

[26] Myers T. Anatomy trains: myofasziale leitbahnen (für Manual- und Bewegungstherapeuten). Berlin: Elsevier Health Sciences Germany; 2015.

[27] Richter P, Hebgen E. Triggerpunkte und muskelfunktionsketten in der osteopathie und manuellen therapie. Stuttgart: Hippokrates-Verlag; 2007.

[28] Tittel K. Beschreibende und funktionelle anatomie. München: Kiener-Verlag; 2016.

[29] Buisseret-Delmas C, Compoint C, Delfini C, Buisseret P. Organisation of reciprocal connections between trigeminal and vestibular nuclei in the rat. J. Comp. Neurol. 1999;409(1):153–68 Epub 1999/06/11. doi:10.1002/(sici)1096-9861(19990621)409:1<153::aid-cne11>3.0.co;2-#. PubMed PMID: 10363717.

[30] Pinganaud G, Bourcier F, Buisseret-Delmas C, Buisseret P. Primary trigeminal afferents to the vestibular nuclei in the rat: existence of a collateral projection to the vestibulo-cerebellum. Neurosci Lett 1999;264(1–3):133–6 Epub 1999/05/13PubMed PMID: 10320032. doi:10.1016/s0304-3940(99)00179-2.

[31] Tecco S, Polimeni A, Saccucci M, Festa F. Postural loads during walking after an imbalance of occlusion created with unilateral cotton rolls. BMC Res Notes 2010;3:141 Epub 2010/05/27PubMed PMID: 20500818; PubMed Central PMCID: PMCPMC2887904. doi:10.1186/1756-0500-3-141.

[32] Oliveira SSI, Pannuti CM, Paranhos KS, Tanganeli JPC, Lagana DC, Sesma N, et al. Effect of occlusal splint and therapeutic exercises on postural balance of patients with signs and symptoms of temporomandibular disorder. Clin Exp Dental Res 2019;5(2):109–15 Epub 2019/05/03PubMed PMID: 31049212; PubMed Central PMCID: PMCPMC6483066. doi:10.1002/cre2.136.

[33] Abubaker AO, Raslan WF, Sotereanos GC. Estrogen and progesterone receptors in temporomandibular joint discs of symptomatic and asymptomatic persons: a preliminary study. J Oral Maxillofacial Surgery: Off J Am Assoc Oral Maxillofacial Surg 1993;51(10):1096–100 Epub 1993/10/01PubMed PMID: 7692023.

[34] Bush FM, Harkins SW, Harrington WG, Price DD. Analysis of gender effects on pain perception and symptom presentation in temporomandibular pain. Pain 1993;53(1):73–80 Epub 1993/04/01PubMed PMID: 8316393.

[35] Conti PC, Ferreira PM, Pegoraro LF, Conti JV, Salvador MC. A cross-sectional study of prevalence and etiology of signs and symptoms of temporomandibular disorders in high school and university students. J Orofac Pain 1996;10(3):254–62 Epub 1996/07/01PubMed PMID: 9161230.

[36] Farenc I, Rougier P, Berger L. The influence of gender and body characteristics on upright stance. Ann. Hum. Biol. 2003;30(3):279–94 Epub 2003/07/10PubMed PMID: 12850961. doi:10.1080/0301446031000068842.

[37] Maurer C, Federolf P, von Tscharner V, Stirling L, Nigg BM. Discrimination of gender-, speed-, and shoe-dependent movement patterns in runners using full-body kinematics. Gait Posture 2012;36(1):40–5 Epub 2012/02/07PubMed PMID: 22304784. doi:10.1016/j.gaitpost.2011.12.023.

[38] Nigg BM, Baltich J, Maurer C, Federolf P. Shoe midsole hardness, sex and age effects on lower extremity kinematics during running. J Biomech 2012;45(9):1692–7 Epub 2012/04/18PubMed PMID: 22507350. doi:10.1016/j.jbiomech.2012.03.027.

[39] Cruz-Gomez NS, Plascencia G, Villanueva-Padron LA, Jauregui-Renaud K. Influence of obesity and gender on the postural stability during upright stance. Obes Facts 2011;4(3):212–17 Epub 2011/06/28PubMed PMID: 21701237. doi:10.1159/000329408.

[40] Loram ID, Maganaris CN, Lakie M. Human postural sway results from frequent, ballistic bias impulses by soleus and gastrocnemius. J Physiol 2005;564(Pt 1):295–311 Epub 2005/01/22PubMed PMID: 15661824; PubMed Central PMCID: PMCPMC1456055. doi:10.1113/jphysiol.2004.076307.

[41] Puszczalowska-Lizis E, Bujas P, Jandzis S, Omorczyk J, Zak M. Inter-gender differences of balance indicators in persons 60-90 years of age. Clin Interv Aging 2018;13:903–12 Epub 2018/05/23PubMed PMID: 29785097; PubMed Central PMCID: PMCPMC5955023. doi:10.2147/cia.S157182.

[42] Bussey MD, Castro MP, Aldabe D, Shemmell J. Sex differences in anticipatory postural adjustments during rapid single leg lift. Hum Mov Sci 2018;57:417–25 Epub 2017/10/22PubMed PMID: 29054327. doi:10.1016/j.humov.2017.10.003.

[43] Chiu M-C, Wu H-C, Chang L-Y. Gait speed and gender effects on center of pressure progression during normal walking. Gait Posture 2013;37(1):43–8. doi:10.1016/j.gaitpost.2012.05.030.

[44] Chung MJ, Wang MJ. Gender and walking speed effects on plantar pressure distribution for adults aged 20-60 years. Ergonomics 2012;55(2):194–200 Epub 2011/08/20PubMed PMID: 21851292. doi:10.1080/00140139.2011.583359.

[45] Telfer S, Bigham JJ. The influence of population characteristics and measurement system on barefoot plantar pressures: a systematic review and meta-regression analysis. Gait Posture 2019;67:269–76 Epub 2018/11/06PubMed PMID: 30391749. doi:10.1016/j.gaitpost.2018.10.030.

[46] Pedroni CR, De Oliveira AS, Guaratini MI. Prevalence study of signs and symptoms of temporomandibular disorders in university students. J Oral Rehabil 2003;30(3):283–9 Epub 2003/02/18PubMed PMID: 12588501.

[47] Gesch D, Bernhardt O, Alte D, Schwahn C, Kocher T, John U, et al. Prevalence of signs and symptoms of temporomandibular disorders in an urban and rural German population: results of a population-based study of health in Pomerania. Quintessence Int (Berlin, Germany: 1985) 2004;35(2):143–50 Epub 2004/03/06PubMed PMID: 15000638.

[48] Wahlund K. Temporomandibular disorders in adolescents. Epidemiological and methodological studies and a randomized controlled trial. Swedish Dental J Suppl 2003(164):2–64 inside front coverEpub 2004/01/14PubMed PMID: 14717039.

[49] Koc D, Dogan A, Bek B. Effect of gender, facial dimensions, body mass index and type of functional occlusion on bite force. J Appl Oral Sci: revista FOB 2011;19(3):274–9 Epub 2011/06/01PubMed PMID: 21625746; PubMed Central PMCID: PMCPMC4234342.

[50] Quiudini PR Jr, Pozza DH, Pinto ADS, de Arruda MF, Guimaraes AS. Differences in bite force between dolichofacial and brachyfacial individuals: side of mastication, gender, weight and height. J Prosthodont Res 2017;61(3):283–9 Epub 2016/11/22PubMed PMID: 27866879. doi:10.1016/j.jpor.2016.10.003.

[51] Seligman DA, Pullinger AG, Solberg WK. The prevalence of dental attrition and its association with factors of age, gender, occlusion, and TMJ symptomatology. J. Dent. Res. 1988;67(10):1323–33 Epub 1988/10/0110.1177/00220345880670101601PubMed PMID: 3049715.

[52] Alshali RZ, Yar R, Barclay C, Satterthwaite JD. Sagittal condylar angle and gender differences. J Prosthodontics: J Am College Prosthodontists 2013;22(7):561–5 Epub 2013/04/05PubMed PMID: 23551923. doi:10.1111/jopr.12047.

[53] Ries LG, Berzin F. Analysis of the postural stability in individuals with or without signs and symptoms of temporomandibular disorder. Braz Oral Res 2008;22(4):378–83 Epub 2009/01/17PubMed PMID: 19148396.

[54] Ringhof S, Leibold T, Hellmann D, Stein T. Postural stability and the influence of concurrent muscle activation–Beneficial effects of jaw and fist clenching. Gait Posture 2015;42(4):598–600 Epub 2015/09/20PubMed PMID: 26385200. doi:10.1016/j.gaitpost.2015.09.002.

[55] Souza JA, Pasinato F, Correa EC, da Silva AM. Global body posture and plantar pressure distribution in individuals with and without temporomandibular disorder: a preliminary study. J Manipulative Physiol Ther 2014;37(6):407–14 Epub 2014/08/12PubMed PMID: 25108750. doi:10.1016/j.jmpt.2014.04.003.

[56] Bumann A, Mah J, Lotzmann U. TMJ disorders and orofacial pain: the role of dentistry in a multidisciplinary diagnostic approach. Stuttgart: Georg Thieme Verlag; 2002.

[57] Gawlak D, Manka-Malara K, Kaminski T, Luniewska M, Mierzwinska-Nastalska E. Comparative evaluation of custom and standard boil and bite (self-adapted) mouthguards and their effect on the functioning of the oral cavity. Dental Traumatol: Off Publ Int Assoc Dental Traumatol 2016;32(5):416–20 Epub 2016/03/08PubMed PMID: 26948149. doi:10.1111/edt.12269.

[58] Gage CC, Huxel Bliven KC, Bay RC, Sturgill JS, Park JH. Effects of mouthguards on vertical dimension, muscle activation, and athlete preference: a prospective cross-sectional study. Gen Dent 2015;63(6):48–55 Epub 2015/11/07PubMed PMID: 26545275.

[59] Ferreira GB, Guimaraes LS, Fernandes CP, Dias RB, Coto NP, Antunes LAA, et al. Is there enough evidence that mouthguards do not affect athletic performance? A systematic literature review. Int Dent J 2019;69(1):25–34 Epub 2018/05/29PubMed PMID: 29808910. doi:10.1111/idj.12406.

[60] Ebben WP. A brief review of concurrent activation potentiation: theoretical and practical constructs. J Strength Condit Res 2006;20(4):985–91 Epub 2006/12/30PubMed PMID: 17194254. doi:10.1519/r-19375.1.