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Comparison of peak pressure, maximum force, contact area and contact time between right and left feet in elite weightlifters

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Abstract

Background and purpose: Since sports activities are likely to be change parameters of plantar pressure distribution during walking, thus the purpose of this study was to the comparison of peak pressure, maximum force, contact area and contact time between right and left foot and their correlation with height and weight in elite weightlifters.

Methodology: The subjects include 12 elite weightlifters with a mean and standard deviation of age 23.2 ± 2.26 years. The parameters of plantar pressure distribution were measured using the Emed platform during barefoot walking. Using Automask software, the sole was divided into ten anatomical regions. The parameters of peak pressure, maximum force, contact area and contact time in each region were obtained using Multimask evalution software. A Paired t-test and the Pearson correlation were used to analyzed data ($p \leq 0.05$).

Results: Our results show that there was significant differences in the peak pressure parameter in

the 3rd region (medial midfoot) and in the maximum force parameter in the 9th region (9th toe) between the right and left feet. Also, a significant positive correlation between height and weight with all the parameters (peak pressure, maximum force, contact area and contact time) were found (P<0.01). In the left foot, there was a significant inverse correlation between maximal force and height in the 5th region (1st metatarsal bone) (P <0.05).

Conclusion: According to the findings, it can be claimed that the functional demand for both feet in weightlifting is very close. Insole designers are also recommended to pay special attention to reducing the load on the third to fifth metatarsal bones to prevent athletes from suffering from complications such as metatarsalgia over the long term.

Keywords: Peak pressure, Maximum force, Contact area, Contact time, Weightlifting.

1. Background

The human foot is the most specialized structure combined with complex biomechanics which allows the person to perform the functions of displacement and maintain balance which this critical role in the proper distribution of times over the musculoskeletal system is reflected in both static and dynamic conditions (1). Gait is a basic requirement for daily activity (1) and is known to be one of the most universal and complex of all human activities (2), for this reason, gait has attracted the attention of many researchers, especially in the field of biomechanics. Measurement of plantar pressure provides an indicator of ankle and foot function during walking and other functional activities because the foot and ankle provide both the support and flexibility needed to tolerate and transfer weight during activities and exercise (3, 4, 5). Although plantar pressure data have been recognized as an important element in the assessment of clients with diabetes and peripheral neuropathy, information derived from plantar pressure data also can assist in determining and managing the impairments associated with various musculoskeletal, integumentary, and neurological disorders (6). Examining the plantar pressure during walking plays an important role in anticipating, depicting, treating and correcting the problems of

those who feel uncomfortable in the area of their feet, or the future may have abnormalities in the area of the sole of their feet (6). The results of various studies indicate the effect of different types of sports activities on foot architecture and structure (1), as well as the pattern of plantar pressure distribution in athletes of different sports (7, 8, 9, 10, 11). Aydos (2011) measured the foot pressure in the 27 Turkish national team wrestlers, and show that peak pressure values for wrestlers were located below the thumb, second metatarsal bone, heel, third to fifth metatarsal bones, first metatarsal bone, second toe, and the least pressure was in the midfoot and the third to fifth toes (7). Zvonar et al. (2012) compared the distribution of plantar pressure in karate performers who performed at the soft (tatami) and the hard (solid) floor. Their results indicated that there was a difference in the forming of the longitudinal and transverse arch between the two groups (11). Yang Lee and Hertler (2012) studied the distribution of pressure in the hind foot, midfoot, and forefoot areas in the runners who had been injured in this sport, they reported a significant correlation between injuries caused by overuse and increased pressure in the heel region (10). Uzun et al. (2012) studied the effect of soccer on the parameters of the contact surface and the maximum forces at the foot of the female football players and non-athlete healthy girls while walking (9). The results of their study showed a significant difference in some parameters of plantar pressure distribution in some anatomical region between the foot of the football player and the non-athlete group. The contact area in the right foot in the lateral heel and midfoot regions and the left foot in the medial and lateral heel regions were significantly different between the athlete and non-athlete groups. Also, the maximum force in the right foot was significantly different between the athlete and the non-athlete group in the lateral heel and midfoot regions and in the left foot in the midfoot, forefoot (toe bones) regions and the second to fourth fingers(9). According to previous researches, plantar pressure patterns are associated with various structural and functional factors, as well as with athletes' injury. Among the structural factors, there can be a significant and positive correlation between peak pressure, maximum force, contact area, and contact time with height and weight (except in the heel area) of wrestlers' (8). Also, the correlation between total peak pressure and weight during walking (15), positive and weak correlation between body mass and maximum plantar pressure was noted in the lateral area of the foot (16) and the medial front area (17). There is a positive relationship between the velocity of gait and peak plantar pressure (12), and treadmill velocities and slopes with peak plantar pressure at the heel, toe and medial leg edges (14).

Weightlifting as a complex and explosive field requires that athletes put weight and pressure beyond their weight on the limbs and in particular on the floor of their feet, which is sometimes twice as high as the athlete's body weight (1). Also due to the deviation of the center of gravity from its normal alignment during weight lifting and barbell, the maximum force and the pressure on the foot shift towards the other side of the anatomical area,

which is not in accordance with the normal pattern of distribution of pressure and force on the floor of the foot. Therefore, it is believed that the distribution plantar pressure pattern in weightlifters is different from the pattern mentioned for athletes of other sports and non-athletic healthy individuals which is mentioned in previous studies. Therefore, the evaluation of the pattern of the plantar pressure distribution and also determining areas exposed to excessive pressure and force and the design of footwear and insole fits these patterns, in the prevention of the damage caused by excessive force and spot pressure on the areas of the foot is very useful and necessary.

There is a consensus between the researchers about the impact of various sports on architecture and foot structure and it has been accepted that different sports activities have different effects on the foot structure and gait pattern, (1,7-11). Also, previous studies have shown a lot of variation in the role and morphology of the foot through the features of age, gender, race, occupation and field and level of sports activities of individuals (1).

Therefore the purpose of this study was to the comparison of peak pressure, maximum force, contact area and contact time between right and left foot in elite weightlifters.

2. Methods

The subjects include 12 elite weightlifters (who had at least 7 years of weightlifting experience) with mean and standard deviation of age 23.2 ± 2.26 years, weight 95.27 ± 2.95 kg and height 178.4 ± 7.5 cm. All subjects completed the consent form. According to the self-reported questionnaire completed by the subjects, none of them had structural abnormalities and history of surgery in the lower extremities and they have not been injured in the last six months.

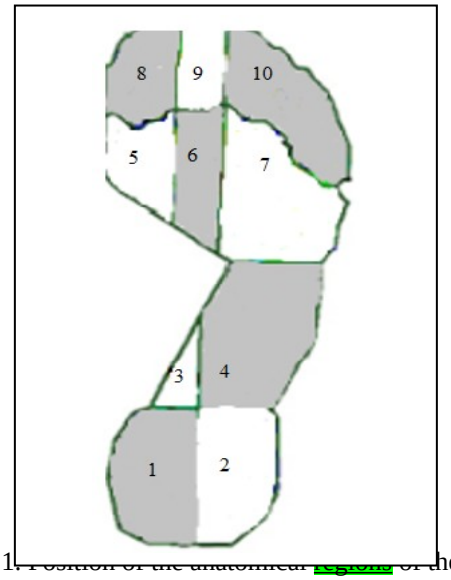
The Emed platform (AT-2 Novel GmbH, Munich, Germany) was used to measure plantar pressure which the reliability of this device has already been proven (18). The Emed platform was placed in the center of the corridor with a length of 10 meters. Subjects were asked to walk along the corridor at a normal speed.

If the subjects placed their foot in the center of the platform without changing the normal walking pattern, this repetition was recorded as a successful repeat for them. Three successful repetitions were required for each foot. From these three successful repetitions, the mean was obtained (by Average software). Also using Automask software, the soles of each foot were divided into ten anatomical regions (Fig. 1). These anatomical regions include M01(medial heel), M02 (lateral heel), M03 (medial midfoot), M04 (lateral midfoot), M05 (1st metatarsal head), M06 (2nd metatarsal head), M07 (3rd, 4th, and 5th metatarsals head), M08 (big toe or thumb), M09 (second toe) and M10 (toes 3, 4, and 5). The parameters that were calculated in each area using the Multimask Evaluation software, including peak pressure (kPa), maximum force (%BW), contact area (cm2) and contact time (ms). Pressure (p) is defined as force(f) per unit area or region (a) (ie, p=f/a) (6). Force, when measured using a force

platform, is the net result of the 3 components of the ground reaction or resultant force acting on the foot (6). The area refers to the amount of surface contact between the plantar surface of the foot and the sensor (6).

2-1. Statistical analysis

Mean and standard deviation was used to describe the data. The data normality was examined using a Kolmogorov-Smirnov test. A Paired t-test was used to compare parameters in right and left foot in each anatomical region. Correlation between variables was determined by the Pearson correlation coefficient (P≤0.05).



1. **Medial Heel**
2. **Lateral Heel**
3. **Medial Midfoot**
4. **Lateral Midfoot**
5. **1st Metatarsal Head**
6. **2nd Metatarsal Head**
7. **3, 4 and 5th Metatarsal Head**
8. **Big Toe**
9. **Second Toe**
10. **Toe 3. 4 and 5**

Figure 1. Position of the anatomical regions of the foot

3. Results

Table 1 presents descriptive data including mean and standard deviation of the pressure distribution variables including peak pressure, maximum force, contact area, and contact time of the subjects' right and left foot.

According to our finding, the maximum force in the right and left feet was highest in region 7 (3rd, 4th and 5th metatarsal heads) and had the lowest in the right foot in region 9 (second toe) and the left foot in region 10 (toes 3, 4 and 5) (Table 1). Peak pressure in the left and right feet in region 7 (3, 4 and 5th metatarsal head) was highest and in region 10 (Toe 3, 4 and 5) the lowest value was shown (Table 1). The contact area in the right and left feet in region 4 (lateral midfoot) and in region 9 (second toe) were the highest and lowest, respectively (Table 1).

The contact time in the right and left feet were highest in region 7 (3rd, 4th, and 5th metatarsal head), and in the right foot in region 3 (medial midfoot) and the left foot in region 4 (lateral midfoot), the lowest values were (Table 1).

Table 2 shows the correlation between the pressure distribution variables with height and weight. Overall, there was a significant correlation between body weight and contact time in most anatomic regions of the foot. However, there was a significant correlation between body weight and maximum force in the least anatomical regions. There was also a significant correlation between height and contact area and contact time, respectively, in the highest and lowest number of anatomical regions (Table 2).

A comparison of the parameters of peak pressure, maximum force, contact area and contact time between the subjects' right and left feet is illustrated in table 3. There is a significant difference between the right and left feet in the maximum force variable in region 9 (second toe) and the maximum pressure variable in region 3 (medial midfoot) (Table 3). No significant difference was found between the right and left foot in the contact area and contact time in the anatomical regions of the sole (Table 3).

4. Discussion

The purpose of this study was to comparison of peak pressure, maximum force, contact area and contact time between right and left feet in elite weightlifters. In this study, according to the results of previous studies that demonstrated the preference of the dynamic state vs. static in the evaluation of plantar pressure, assessments in dynamic status and without footwear on the plantar pressure measurement device was performed (8, 20). Based on the findings of this study, there was a significant difference between the right and left feet in the maximum force in region 9 (second toe) and in the peak pressure variable in region 3 (medial midfoot) whose values on the left foot were greater than the right foot. A study on weightlifters that could compare the results of this study was not found and for this reason, similar studies have been used in other fields of sport. In this study, the pattern of maximum force in the right and left feet was the same, so that the thumb had the highest amount of force between the toes. The pattern of maximum force increase in the region of the forefoot, midfoot and heel from the inside to the outside, which this increase was very noticeable in the region of the metatarsal bones. Also, the highest maximum force was applied to region 7 (3rd, 4th, and 5th metatarsal head) and the lowest amount was entered into the second to fifth toes.

According to the findings of this study, the pattern of pressure distribution in the right and left feet of the subjects were identical, so that in both feet, the highest pressure was applied to the third to fifth metatarsal bones, and the lowest amount was entered into the third to fifth toes.

In the study of Memer and Noori (2017) and Idas (2011) on wrestlers, the lowest pressure on the third to fifth toes was found, which is consistent with the current study (7,8). But studies on non-athletic healthy people suggested that the lowest pressure is on the midfoot and the highest pressure on the thumb (21) and some of the

researchers have introduced heels (22) have been described as being the highest pressure amount bearing location that does not in line with the current study. The researcher attributes this contradiction to the effect of exercise on the pattern of gait in athletes and as a consequence of the effect on the pattern of plantar pressure distribution. Also, in the other studies the presence of significant differences between elite athletes and healthy non-athlete subjects in beginner group in the factors of the plantar pressure distribution pattern was reported (9, 23).

The pattern of pressure increase was in the midfoot and the metatarsal bones from the inside to the outside. In the heel region, almost the same pressure was applied to the medial and lateral regions. In the region of the toes, respectively, the thumb, the second toe, and then the third to fifth toes, tolerated the highest pressure. This finding is consistent with the study of Memar and Noori (2017) and Aydos (2011) (8,7). The contact area shows its highest amount in the midfoot and the lowest in the second toe region. The contact area in the medial heel is greater than the lateral heel and in the lateral midfoot there is a considerable increase relative to medial midfoot. In the metatarsal bones region, the 2nd metatarsal, 1st, and then the third to fifth metatarsal bones, respectively, had the highest amount. Also, thumb, third to fifth toes and at the end second toe were the highest. Contact time is one of the most important parameters for showing different walking conditions and foot problems (24). The contact time was highest in the region of the third to fifth metatarsal bones and had the smallest amount in the medial midfoot on the right foot and lateral midfoot on the left foot. more contact time in the forefoot, probably is due to the greater flexibility of the medial longitudinal arch and the weakness of the ligaments in this region (25), this is due to the degree of flatfoot that is present in all athletes to some extent. The reason for the low contact time in the midfoot, the rapid passage of the body weight after the heel, from the midfoot (areas 3 and 4) to the forefoot (metatarsal bones) (27).

In some sports, feet may not have the same duties and functions and on the other hand, there is no dominant and non-dominant foot in the performance skills of a particular sports, which in these sports, the difference in the pattern of the distribution of plantar pressure between the dominance and non-dominance foot is not unexpected. For example, Wong et al. (2007) evaluate the distribution of plantar pressure between the dominant and non-dominant foot of the soccer players in exclusive moves, and the results indicated a difference in the distribution of pressure between the dominant and non-dominant limbs (28). However, Memear and Noori (2017) compared the right and left feet pattern of plantar pressure distribution in elite wrestlers and only reported significant differences in the contact area variable in the lateral midfoot between the right and left feet and in the maximum force, peak pressure and contact time variables did not mention significant differences (8). In the present study, the feet showed very close patterns of distribution of maximum force, peak pressure, contact area and contact

time in the right and left feet. The reason for this can be attributed to the lack of dominant foot and the identical movement pattern of the feet in this sport. This study also investigates the correlation between maximum force, peak pressure, contact area, and contact time with height and weight. According to the findings of this study, there was a positive and significant correlation between height and weight variables with peak pressure, maximum force, contact area and contact time in right and left feet and the only maximum force with height in region 4 (lateral midfoot) had a reverse correlation. The results are consistent with the findings of the study of Memar and Noori (2017) and Aydos (2011) on wrestlers regarding the existence of a positive and significant correlation between height and weight with maximum force, peak pressure, contact area and contact time. Also, Uzun et al. (2012) in soccer girls and non-athletic healthy girls show the positive and significant relationship between height and weight with contact area (9.8.7). Henning and Milani (1993) and Snow and colleagues (1992) reported a positive correlation between body weight and peak pressure in the lateral region of the foot (16) and the medial forefoot (17), which is consistent with the findings of this study.

4-1. Conclusion

Based on the findings of this study, it can be stated that the feet in weightlifting have the same functional duties and the same pattern of motion, this leads to the emergence of the same pattern of distribution of force and pressure on the plantar of both right and left feet. The pattern obtained in this study is different from the pattern that has conducted on non-athlete healthy subjects and studies performed on other sports, which confirms the effect of different sports activities on the pattern of distribution of plantar pressure. Since one of the goals of measuring the distribution of plantar pressure is clinical evaluation, based on the results obtained, it is recommended insoles designers in the design of shoe weightlifters pay special attention to decrease point load under third to fifth metatarsal bones to prevent the onset of side effects in athletes such as metatarsalgia and other complications associated with increased point pressure on the plantar of the foot in the long term.

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Table 1. Descriptive data including mean and standard deviation of peak pressure, relative maximum force, contact area and contact time in right and left feet

		Peak pressure (Kpa)	Maximum force (BW%)	Contact area (cm^2)	Contact time (ms)
Anatomical area		Average (standard deviation)	Average (standard deviation)	Average (standard deviation)	Average (standard deviation)
Mask 1	Right foot	257 (55.28)	29.97 (7.75)	19.32 (3.09)	555.27 (52.10)
	Left foot	281 (61.25)	30.15 (5.33)	19.16 (2.81)	536.03 (63.20)
Mask 2	Right foot	262.5 (45.27)	26.03 (4.94)	19.26 (3.15)	557.17 (55.25)
	Left foot	279 (52.25)	27.61 (6.23)	19.1 (2.96)	536.02 (63.18)
Mask 3	Right foot	126 (36.08)	3.6 (4.68)	10.15 (7.60)	519.02 (93.33)
	Left foot	139 (41.48)	3.43 (4.07)	9.07 (5.92)	497.12 (80.53)
Mask 4	Right foot	156 (55.65)	22.08 (6.62)	30.15 (6.87)	645.75 (69.15)
	Left foot	165 (74.81)	23.08 (9.52)	31.07 (6.73)	450.74 (53.75)
Mask 5	Right foot	205 (56.45)	16.44 (7.73)	16.65 (4.03)	693.18 (65.5)
	Left foot	214 (101.5)	16.42 (7.13)	16.87 (3.93)	659.36 (61.72)
Mask 6	Right foot	360 (100.95)	24.35 (7.27)	15.20 (4.16)	732.16 (55.08)
	Left foot	369 (113.13)	23.84 (4.63)	15.18 (3.65)	698.32 (51.09)
Mask 7	Right foot	407 (183.06)	45.63 (10.71)	27.14 (2.09)	745.62 (53.59)
	Left foot	362.5 (108.77)	47.57 (16.91)	28.00 (2.77)	724.30 (43.71)
Mas 8	Right foot	222 (114.08)	13.94 (6.76)	12.30 (2.59)	602.18 (120.1)
	Left foot	244 (97.20)	13.53 (3.19)	11.81 (1.84)	591.03 (102.49)
Mask 9	Right foot	120.5 (66.39)	2.19 (0.72)	5.10 (1.19)	519.11 (130.04)
	Left foot	129.5 (46.87)	2.81 (0.58)	5.34 (0.87)	510.40 (66.9)
Mask 10	Right foot	78.5 (30.73)	2.52 (1.16)	8.15 (2.18)	562.8 (152.59)
	Left foot	84 (31.95)	2.68 (1.30)	8.1 (2.55)	570 (100.2)

Table 2. Pearson correlation coefficient between height and weight with peak pressure, maximum force, contact area and contact time in the right and left feet of the subjects

		Peak pressure (Kpa)		Maximum force (BW%)		Contact area (cm^2)		Contact time (ms)	
Anatomical area		Average (standard deviation)		Average (standard deviation)		Average (standard deviation)		Average (standard deviation)	
		Pearson correlation P(r)		Pearson correlation P(r)		Pearson correlation P(r)		Pearson correlation P(r)	
		height	weight	height	weight	height	weight	height	weight
Mask 1	Right foot	0.44 (-0.119)	0.29 (-0.126)	0.36 (-0.123)	0.21 (-0.350)	0.08 (**0.776)	0.0 (**0.929)	0.97 (0.553)	0.06 (** 0.798)
	Left foot	0.05 (-0.044)	0.06 (0.187)	0.18 (-0.084)	0.8 (-0.102)	0.06 (**0.796)	0.01 (**0.879)	0.06 (0.542)	0.1 (*0.763)
Mask 2	Right foot	0.57 (-0.020)	0.12 (-0.040)	0.82 (-0.311)	0.94(-0.558)	0.09 (**0.769)	0.01 (**0.869)	0.72 (0.592)	0.02 (**0.841)
	Left foot	0.54 (-0.067)	0.61 (0.159)	0.00 (-0.140)	0.6 (-0.111)	0.07 (**0.786)	0.01 (**0.878)	0.06 (0.542)	0.1 (*0.763)
Mask 3	Right foot	0.11 (0.535)	0.14 (0.431)	0.90 (0.306)	0.18 (0.353)	0.28 (0.419)	0.16 (0.529)	0.83 (0.574)	0.10 (**0.765)
	Left foot	0.40 (0.501)	0.51 (0.489)	0.00 (0.140)	0.44 (0.219)	0.82 (0.311)	0.63 (0.478)	0.81 (0.576)	0.05 (**0.8)
Mask 4	Right foot	0.005(**0.806)	0.06(**0.793)	0.1(**0.768)	0.97 (0.553)	0.07 (**0.768)	0.12 (*0.751)	0.08 (0.539)	0.34 (*0.669)
	Left foot	0.37 (0.504)	0.5 (0.331)	0.85(0.375)	0.23 (0.129)	0.24 (*0.702)	0.72 (0.592)	0.48 (*0.636)	0.1 (*0.765)
Mask 5	Right foot	0.91 (-0.305)	0.34 (0.03)	0.85(-0.571)	0.93 (-0.370)	0.4 (0.221)	0.06 (0.437)	0.04 (0.090)	0.66 (0.474)
	Left foot	0.95 (-0.094)	0.58 (0.396)	0.37(*-0.662)	0.14 (-0.235)	0.89 (0.373)	0.65 (0.602)	0.51 (0.330)	0.36 (0.665)
Mask 6	Right foot	0.96 (0.302)	0.46 (0.495)	0.55 (-0.021)	0.34 (0.076)	0.4 (*0.654)	0.1 (*0.762)	0.53 (0.114)	0.21 (0.425)
	Left foot	0.98 (0.444)	0.33 (*0.674)	0.13 (0.356)	0.34(*0.671)	0.05(**0.809)	0.04 (**0.810)	0.05 (0.543)	0.03 (0.825)
Mask 7	Right foot	0.11 (*0.761)	0.0(**0.967)	0.7 (0.319)	0.82 (0.252)	0.8 (0.460)	0.38 (*0.660)	0.15 (0.182)	0.81 (0.460)
	Left foot	0.83 (0.459)	0.63 (0.607)	0.7 (0.155)	0.84 (-0.1)	0.75 (0.203)	0.2 (0.351)	0.96 (0.446)	0.10 (*0.762)
Mas 8	Right foot	0.71 (-0.059)	0.35 (-0.507)	0.61(-0.064)	0.77 (-0.583)	0.01 (**0.882)	0.25 (0.518)	0.21 (0.350)	0.91 (0.371)
	Left foot	0.82 (0.101)	0.1 (0.237)	0.33(-0.173)	0.80 (-0.379)	0.10 (*0.764)	0.73 (0.589)	0.49 (0.165)	0.90 (0.372)
Mask 9	Right foot	0.62 (0.478)	0.02(**0.847)	0.70(0.106)	0.18 (0.084)	0.62 (0.393)	0.06 (**0.798)	0.92 (0.144)	0.01 (0.548)
	Left foot	0.70 (0.471)	0.01(**0.870)	0.04(-0.297)	0.02 (-0.241)	0.92 (-0.05)	0.21 (0.179)	0.86 (0.052)	0.17 (0.181)
Mask 10	Right foot	0.57 (0.212)	0.66 (0.474)	0.03 (0.363)	0.18 (0.289)	0.55 (0.622)	0.40 (*0.654)	0.22 (0.082)	0.98 (0.552)
	Left foot	0.48 (*0.637)	0.01(**0.765)	0.28 (-0.033)	0.87 (0.146)	0.50 (0.402)	0.72 (0.591)	0.06 (0.437)	0.88 (0.454)

*: significant correlation in level P≤0.05

**: significant correlation in level P≤0.01

Table 3. The results of t-test between the right and left feet of the subjects in the variables of peak pressure, maximum force, contact area and contact time

	Peak pressure (Kpa)		Maximum force (BW%)		Contact area (cm^2)		Contact time (ms)	
Anatomical area	T	Sig(2-taild)	T	Sig(2-taild)	T	Sig(2-taild)	T	Sig(2-taild)
Mask 1	-2.03	0.55	-0.41	0.91	0.18	0.52	1.99	0.00
Mask 2	1.03	0.23	-1.56	0.77	0.17	0.92	-1.60	0.39
Mask 3	-2.48	*0.23	0.76	0.79	-1.10	0.23	1.20	0.53
Mask 4	0.44	0.68	-0.69	0.58	-1.21	0.91	-0.79	0.53
Mask 5	-0.02	0.70	0.18	0.86	0.44	0.67	2.20	0.63
Mask 6	0.34	0.75	0.81	0.85	0.31	0.76	-2.26	0.53
Mask 7	0.99	0.44	-0.11	0.56	1.31	0.87	1.78	0.49
Mask 8	0.78	0.77	0.08	0.65	1.21	0.34	-0.04	0.96
Mask 9	-0.57	0.28	2.78	*0.35	0.93	0.06	0.88	0.80
Mask 10	0.33	0.07	0.25	0.81	-0.70	0.93	0.69	0.70

*: significant difference

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