Effect of Swiss ball training on abnormal plantar pressure distribution among adolescents with intellectual disabilities

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Abstract

Objective: To explore the difference of plantar pressure distribution between adolescents with intellectual disabilities (ID) and healthy adolescents during gait and the effect of Swiss ball training on plantar pressure of adolescents with ID during gait.

Methods: A total of 12 adolescents with ID participated in a 12-week Swiss ball training (three 40-minute sessions per week), including eight balance training movements. Meanwhile, 10 healthy adolescents did not undergo any intervention. Pre and post-interventions of stride length, stride time, gait speed, relative peak pressure, impulse and gait symmetry of 10 zones of the sole were conducted.

Results: Adolescents with ID had shorter stride length, longer stride time, slower walking speed, excessive plantar peak pressure in heel medial zone, obvious abnormalities in metatarsal 1-3 zone, and significantly lower rearfoot impulse and gait symmetry than healthy adolescents. Adolescents with ID demonstrated increased post-intervention stride length, stride time, walking speed, and improved gait symmetry. Additionally, their peak pressure and impulse indexes were closer to those of healthy adolescents after the intervention.

Conclusion: Abnormal gait phenomena, such as peak pressure, impulse, and gait asymmetry were observed in adolescents with an intellectual disability. Swiss ball training can make plantar pressure distribution more reasonable and improve abnormal gait among adolescents with ID.

Introduction

Mental retardation refers to individuals who have intellectual defects before the age of 18 with obvious difficulties in adapting to social life[1]. A prior study showed that the level of basic motor ability of adolescents with intellectual disabilities (ID) is significantly lower than that of healthy adolescents due to the limitation of intelligence and adaptive function[2]. Intellectually disabled adolescents have serious difficulties in controlling and maintaining balance[3], and they are highly predisposed to abnormal gait during walking[4]. More importantly, intellectual disabilities fail to improve with physical development or age[5].

Abnormal gait is characterised by abnormal plantar pressure. Certain compensatory mechanisms of musculoskeletal systems are elicited following long-term abnormal gait[6]. For instance, deformation of similar joints and increased risk of foot discomfort or pain result from excessive pressure between different areas of the sole[7]. Likewise, the risk of plantar pain is heightened in response to increased peak pressure and impulse of the forefoot during walking. Both lateral and medial heels respond differently to the pressure in the medial area of the foot. Excessive pressure in the latter reduces and increases the pressure at the lateral heel (HL) and medial heel (MF), respectively. These events increase the risk of injury in the middle of the foot[8]. Heel pain is easily elicited since the pressure and impulse at the heel are too large while the pressure centre track at the heel bends and deviates to the inner direction[9]. Therefore, adolescents with ID need to adjust the plantar pressure distribution and reduce the risk of plantar damage.

Balance training is an effective way to improve dynamic plantar pressure [10]. Meanwhile, conventional balance training is monotonous and boring, which is considered unsuitable for the training of adolescents with ID[11]. On the other hand, Swiss ball training increases the body demand for small muscle groups through the unstable plane[12]. Additionally, the Swiss ball training trains one or more muscle groups effectively[13], enhances individual balance ability[13–14] and core stability[15], and improves the range of motion and walking ability of lumbar joints in patients with lumbar disc herniation[16]. Nevertheless, the improvement of plantar pressure distribution of adolescents with ID by Swiss Ball balance training remains unclear.

Using the plantar pressure test system and video analysis, this study explored the temporal and spatial parameters and plantar pressure distribution of adolescents with ID during walking[17]. This study aimed to provide a safe and effective exercise programme to improve the abnormal plantar pressure distribution of adolescents with ID during walking.

Methods

Participants

This study involved 12 adolescents with mild to moderate mental retardation (BAL group)[1] in Qingdao Sanjiang special education school and 12 healthy peers (CON group) in Qingdao Laoshan No. 3 middle school. All participants' health status and medical history were examined, and they were certified to have no cardiopulmonary disease. Both test subjects and their guardians were briefed on the research objectives and procedures. They also read and signed the informed consent form prior to the study. This study was approved by the Special Committee on Scientific Ethics of Ocean University of China (Ethics approval: OUC-HM-2021-012) (see Appendix A).

Study Design

Basic information such as participants' age, weight, intelligence degree, and plantar pressure distribution were collected pre-intervention. After 12 weeks of Swiss ball intervention, the aforementioned indexes were collected again in the BAL group.

Intervention Programme

According to the previous Swiss Ball intervention programme[14], the Swiss ball exercise intervention for adolescents with ID was conducted for 12 weeks. The exercise was divided into three stages, four weeks in each stage, and three training sessions were conducted weekly for 40 minutes, including the warm-up part (5 minutes), the exercise part (30 minutes) and the cool-down part (5 minutes). Both the warm-up and the cool-down parts were performed (jogged) at the speed selected by each participant for five minutes on the treadmill. Swiss ball exercise intervention (see Appendix B) was divided into sitting exercise (No: 1–4), kneeling exercise (No: 5), and lying exercise (No: 6–8). The number of repetitions and groups increased gradually with the intervention duration. A one-minute interval was inserted between each set. According to the 6–20 Borg scale, exercise intensity is the level that subjects feel "A little hard-13". Subjects were informed to stop the exercise and rest if they feel dizzy or have any difficulty during the process (Appendix B)

Intelligence Assessment

Participants' intelligence quotients (IQ) was evaluated using a pre-validated Wechsler Intelligence Scale test pre and post-exercise interventions[18–19]. Participants' IQ measurements were categorised as normal, mild, and moderate if the IQ score ranged from 90 to 114, 50 to 70, and 35 to 49, respectively.

Experimental Instrument

The experimental setup included the Footscan 7 plantar force test system (RSscan international, Belgium), comprising a 2 m × 0.5 m plantar pressure plate, data acquisition box, data line, and analysis software. Four pressure sensors were built in the plantar pressure plate per square centimetre and the sampling frequency was 250 Hz. A high-speed camera (JVC gc-px10ac, China), with a camera height of 1.2 m, a frame rate of 50F/s, and a shutter speed of 1/200s was used in this study.

Gait Test

The subjects' height and weight in the standing state were measured using the calibrated height ruler and weight scale. The plantar pressure test plate was installed in the middle of a 10 m long rubber sidewalk. In order to prevent the subject from being affected by the position of the plate[20], the sidewalk was covered with a top layer made of EVA material (hardness: shore a 70; thickness: 2 mm). The camera was located at an included angle of 90 ° in the walking direction and 5 m vertically away from the flat plate.

Participants walked barefoot through the plantar pressure plate in a natural gait. The test was repeated until three valid data are collected. Participants start walking 5 m in front of the slab. Upon walking through the slab, they walked for another 2 to 3 m. They were asked to familiarise themselves with gait tests at least twice before the formal test. The subjects' spatiotemporal parameters during walking were extracted by the video analysis system (Simi motion V9.2), including complex stride length, stride time, and walking speed. The shorter and longer sides of the stride length were defined as the weak and strong sides, respectively[21].

Parameters

The plantar force test and analysis system were employed to extract the subjects' pressure parameters, such as peak pressure and impulse. The whole plantar area was divided into 10 zones (Fig. 1): Toe 1 (T1), Toe 2 to Toe 5 (T2–T5), Metatarsal 1 (M1), Metatarsal 2 (M2), Metatarsal 3 (M3), Metatarsal 4 (M4), Metatarsal 5 (M5), Midfoot (MF), Heel medial (HM), and Heel lateral (HL).

In order to make the parameters comparable, some parameters were standardised as a percentage of body weight[22]. The calculation formula is as follows:

$$\mathrm{Relativepeakpressure} = \frac{\mathrm{Peakpressure}}{\mathrm{Weight}}$$

The following formula is used to calculate the symmetry index (SI) of gait variables[21] to evaluate the symmetry of gait.

$$\mathrm{SymmetryIndex} = \left|1 - \frac{\mathrm{variablesinstridelengthshortside}}{\mathrm{variablesinstridelengthlongerside}}\right|$$

Statistical analysis

All the data were analysed using the Statistical Package for Social Science (IBM SPSS, Version 23.0). The data were summarised and expressed as mean ± standard deviation. Paired sample t-test was used to compare the gait symmetry index, gait temporal and spatial parameters, peak plantar pressure, and plantar impulse between adolescents with ID and normal peers pre and post-balance training. Statistical significant differences were considered present for P-values less than 0.05.

Results

The comparison of gait temporal and spatial parameters between mentally retarded and healthy adolescents pre and post-intervention is presented in Table 1. Statistical significant differences in stride length, stride time, and walking speed ($P < 0.05$) were observed at pre and post-intervention. Stride length, stride time, and walking speed were significantly different between adolescents with ID and normal peers pre-intervention ($P < 0.05$). Specifically, walking speed was significantly different between adolescents with ID and healthy adolescents post-intervention ($P < 0.05$), nevertheless, no statistical differences in stride length and stride time ($P > 0.05$).

Table 1
Comparison of gait parameters between BAL group and CON group

	BAL		CON
	PRE	POST	
Stride length (m)	$0.88 \pm 0.15^{\#}$	$0.99 \pm 0.13^{*}$	1.05 ± 0.10
Stride time (s)	$0.71 \pm 0.10^{\#}$	$0.62 \pm 0.11^{*}$	0.59 ± 0.02
Walking speed (m/s)	$0.80 \pm 0.18^{\#}$	$1.13 \pm 0.26^{*\#}$	1.70 ± 0.22

*= There is a statistical difference compared with PRE, $P < 0.05$, # = There is a statistical difference compared with the CON group, $P < 0.05$.

Table 2 shows the comparisons of peak plantar pressure between mentally retarded and healthy adolescents pre and post-intervention. The peak plantar pressure on the strong side of adolescents with ID was significantly different in M3, HM, and HL ($P < 0.05$) while T1, M1, M3, HM, and HL ($P < 0.05$) was significantly different on the weak side post-intervention. Compared with healthy adolescents, there were significant differences in M2, M3, HM and HL on the strong side ($P < 0.05$), and in T1, M1, M2, M3, HM and HL on the weak side ($P < 0.05$) pre-intervention. At post-intervention, the strong side showed significant differences in M2, M3, HM and HL ($P < 0.05$) compared with healthy adolescents. Likewise, the weak side demonstrated significant differences in M2, M3, and HM ($P < 0.05$) compared with healthy adolescents post-intervention.

Table 2
Comparison of peak pressure of strong and weak plantar of BAL group and CON group

		BAL		CON
		PRE	POST	
T1 (N/kg)	Strong	1.08 ± 0.83	1.21 ± 0.34	1.83 ± 0.89
	Weak	0.99 ± 0.89#	1.49 ± 0.99*	2.34 ± 0.86
T2-5 (N/kg)	Strong	0.63 ± 0.79	0.54 ± 0.38	0.52 ± 0.34
	Weak	0.62 ± 0.68	0.64 ± 0.29	0.64 ± 0.39
M1 (N/kg)	Strong	1.11 ± 0.87	1.44 ± 0.62	2.16 ± 1.43
	Weak	1.02 ± 0.87#	1.72 ± 0.63*	2.66 ± 1.47
M2 (N/kg)	Strong	1.87 ± 0.95#	2.21 ± 0.75*#	3.49 ± 0.67
	Weak	1.90 ± 1.13#	2.29 ± 0.72#	3.75 ± 0.74
M3 (N/kg)	Strong	1.91 ± 1.00#	2.24 ± 0.57*#	2.81 ± 0.73
	Weak	1.86 ± 1.22#	2.26 ± 0.58*#	2.94 ± 0.60
M4 (N/kg)	Strong	1.82 ± 1.04	1.73 ± 0.37	2.05 ± 0.84
	Weak	1.95 ± 1.12	1.69 ± 0.47	1.71 ± 0.56
M5 (N/kg)	Strong	0.74 ± 0.41	0.83 ± 0.26	1.27 ± 0.89
	Weak	1.06 ± 0.98	0.96 ± 0.66	0.67 ± 0.47
MF (N/kg)	Strong	3.02 ± 1.70	3.39 ± 1.87	4.17 ± 1.67
	Weak	3.08 ± 1.66	3.07 ± 1.81	3.62 ± 1.17
HM (N/kg)	Strong	2.80 ± 1.26#	4.04 ± 0.77*#	4.96 ± 1.17
	Weak	2.94 ± 1.55#	3.90 ± 0.82*#	5.27 ± 1.43
HL (N/kg)	Strong	2.49 ± 1.19#	3.24 ± 0.78*	4.17 ± 1.01
	Weak	2.30 ± 1.13#	3.07 ± 1.18*#	4.10 ± 0.98

*= There is a statistical difference compared with PRE, P￼0.05, # = There is a statistical difference compared with the CON group, P < 0.05.

Table 3 depicts the comparison of plantar impulse between adolescents with ID and healthy adolescents pre and post-intervention. Compared to healthy adolescents, the plantar impulse of adolescents with ID had significant differences in HM division (P < 0.05) on the strong side pre-intervention. The T1, M1, M2, HM, and HL divisions on the weak side were also significantly different ($P < 0.05$) in adolescents with ID compared to the healthy group at pre-intervention. Nonetheless, there was no significant difference in all areas on the strong side ($P > 0.05$) at post-intervention but the T1 area on the weak side was significantly different ($P < 0.05$) between the two experimental groups.

Table 3
Comparison of impulse of strong and weak plantar of BAL group and CON group

		BAL		CON
		PRE	PRE	
T1 (N·s/kg)	Strong	0.38 ± 0.39	0.30 ± 0.14	0.44 ± 0.24
	Weak	0.29 ± 0.26$^{\#}$	0.41 ± 0.17$^{*\#}$	0.62 ± 0.26
T2-5 (N·s/kg)	Strong	0.26 ± 0.40	0.18 ± 0.12	0.16 ± 0.17
	Weak	0.19 ± 0.34	0.19 ± 0.11	0.15 ± 0.08
M1 (N·s/kg)	Strong	0.52 ± 0.49	0.59 ± 0.38	0.61 ± 0.39
	Weak	0.37 ± 0.49$^{\#}$	0.71 ± 0.32*	0.84 ± 0.54
M2 (N·s/kg)	Strong	0.85 ± 0.55	1.13 ± 0.57	1.17 ± 0.36
	Weak	0.79 ± 0.63$^{\#}$	1.11 ± 0.33*	1.36 ± 0.35
M3 (N·s/kg)	Strong	0.77 ± 0.46	1.01 ± 0.43	1.12 ± 0.35
	Weak	0.83 ± 0.52	0.99 ± 0.24	1.10 ± 0.28
M4 (N·s/kg)	Strong	0.70 ± 0.39	0.74 ± 0.24	0.76 ± 0.36
	Weak	0.71 ± 0.37	0.71 ± 0.51	0.64 ± 0.21
M5 (N·s/kg)	Strong	0.24 ± 0.14	0.45 ± 0.19	0.40 ± 0.28
	Weak	0.36 ± 0.29	0.29 ± 0.31	0.23 ± 0.16
MF (N·s/kg)	Strong	1.16 ± 0.85	1.18 ± 1.69	1.28 ± 0.57
	Weak	0.96 ± 0.64	1.07 ± 1.27	1.01 ± 0.33
HM (N·s/kg)	Strong	0.91 ± 0.47$^{\#}$	1.33 ± 0.57*	1.36 ± 0.41
	Weak	0.84 ± 0.47$^{\#}$	1.51 ± 0.76*	1.50 ± 0.75
HL (N·s/kg)	Strong	0.85 ± 0.49	1.01 ± 0.47	1.09 ± 0.31
	Weak	0.67 ± 0.31$^{\#}$	1.05 ± 0.54*	1.07 ± 0.45

*= There is a statistical difference compared with PRE, P□0.05, # = There is a statistical difference compared with the CON group, $P < 0.05$.

The gait symmetry indexes of intellectually disabled and healthy adolescents pre and post-intervention are shown in Table 4. Significant differences were observed in stride length SI, stride time SI, walking speed SI, peak pressure SI, and impulse SI among adolescents with ID ($P < 0.05$) post-intervention. Likewise, all the aforementioned parameters were statistically different between healthy adolescents and those with intellectual disability at pre-intervention ($P < 0.05$). Statistically significant differences were detected in peak pressure SI between healthy and intellectually disabled adolescents post-intervention ($P < 0.05$) but stride length SI, stride time SI, and walking speed SI were statistically different between the groups ($P > 0.05$).

Table 4
Comparison of symmetry index of the gait variables between BAL group and CON group

	BAL		**CON**
	PRE	**POST**	
Stride length	0.10 ± 0.07#	0.05 ± 0.06*	0.04 ± 0.02
Stride time	0.13 ± 0.11#	0.08 ± 0.06*	0.07 ± 0.05
Walking speed	0.10 ± 0.07#	0.05 ± 0.06*	0.03 ± 0.03
Peak pressure	0.29 ± 0.20#	0.21 ± 0.19*#	0.10 ± 0.07
Impulse	0.43 ± 0.31#	0.22 ± 0.15*	0.13 ± 0.08

*= There is a statistical difference compared with PRE, P⍰0.05, # = There is a statistical difference compared with the CON group, $P < 0.05$.

Discussion

Most intellectually disabled individuals have an abnormal gait and a higher risk of foot discomfort or pain during walking[7]. Hence, these individuals need to reduce the plantar pressure distribution in order to minimise the risk of plantar damage. The present study elucidates the effect of balance training on the abnormal dynamic plantar pressure distribution of adolescents with ID. Specifically, Swiss ball training was introduced to make them train safely and effectively. The results revealed the potential positive impact of the exercise intervention on abnormal plantar pressure distribution of intellectually disabled adolescents.

In this study, the stride length of adolescents with ID was significantly shorter, the stride time was longer, and the pace was slower compared to that of healthy adolescents. These findings could be attributed to various defects in the vestibular[23], visual[24], and proprioceptive systems of adolescents with ID[25]. These events have been suggested to contribute to lower balance abilities in intellectually disabled individuals compared to healthy groups[26]. Thus, individuals with intellectual disabilities need to shorten their stride length to reduce the lateral displacement of the body centre of gravity during walking.

Meanwhile, longer stride time and slower walking speed are more conducive for mentally retarded teenagers to maintain their body stability during locomotion[4, 10].

Different zones of the sole are subjected to specific vertical forces as the foot makes contact with the ground. Exploring the peak pressure of various zones of the sole is pertinent to understanding the force changes of the foot in the gait process. In the present study, the average plantar peak pressure value on the strong and weak sides of adolescents with ID was lower than that of healthy adolescents before the intervention. These results indicate that intellectually disabled adolescents possessed lower limb strength. Such individuals find it difficult to control their body posture balance during walking due to lower muscle strength, weaker integration and coordination of vestibular, visual, and proprioceptive systems[2, 27]. Resultantly, the body’s barycentre is unable to move forward continuously, especially during single-leg support. Given the limitation of the ankle joint, the hip joint is used to maintain balance, thereby resulting in the lateral displacement of the barycentre[28]. Previous studies have shown that foot pressure is increased with a decrease in balance[29], which is consistent with the present results.

The cumulative effect of the continuous force in different foot areas at certain periods is reflected by the foot impulse during walking and it is the joint action of pressure and time. In this study, weakened balance activity might be responsible for the significantly lower HM and HL zoning impulse of adolescents with ID at pre-intervention compared to that of healthy adolescents. The possible underlying mechanisms have been suggested in previous studies. For instance, the centre of gravity moves forward quickly after the heel touches the ground. This event makes the load on the heel move forward quickly[30] and it takes a longer time to rotate back[6]. Hence, a large average impulse value is elicited in the MF zone while pedalling off the ground. As depicted in Appendix C-A and C-B, healthy teenagers mainly rely on the inner side of the heel and forefoot while the force of the second to fifth toes is very small. The lines of the whole foot figure are relatively smooth, indicating that the centre of gravity moves forward and smoothly during walking. Before the intervention, adolescents with ID relied mostly on the lateral and midfoot force. Nevertheless, the midfoot force was significantly improved post-intervention. This was evident as the internal and external sides of the forefoot force in the intellectually disabled adolescents were more average and the characteristics of the 3D figure post-intervention were similar to those of healthy adolescents.

Symmetry index (SI) is often considered an important index to evaluate gait quality[21, 31]. In this study, the symmetry of gait parameters of adolescents with ID was low, which may be due to functional asymmetry and control interruption[32]. The ability to balance depends on the coordination of vision, proprioception, and vestibular perception by the central system and the control of motor effectors [33]. The balance level of healthy adolescents reaches the adult level around 12 years old[34], whereas that of adolescents with ID lag behind their peers[27] and it does not improve with age[34]. Nonetheless, the stability of the vestibular system and proprioceptive sensitivity can be improved through acquired training[35–36]. Balance training with Swiss ball can effectively improve the balance ability of adolescents with ID[37]. These individuals demonstrated improvements in their vestibular, visual, and proprioceptive systems through Swiss ball training intervention. Additionally, the strength of lower limbs and balance ability was enhanced which was linked to improved adjustment ability of body posture control and posture change [35–36]. the symmetry of temporal and spatial parameters of gait and plantar pressure was also enhanced in response to an increase in the stride length, reduced stride time, and accelerating pace.

Conclusion

Conclusively, adolescents with ID are characterised by small stride length, long stride time, and slow walking speed, which might be associated with their low balance ability. These individuals demonstrated significant differences in plantar peak pressure and impulse compared to normal and healthy adolescents. Overall, the Swiss ball training was effective in improving the plantar pressure distribution and gait asymmetry of adolescents with ID.

Declarations

Ethics approval and consent to participate

The study protocol includes human participants and human data. This study and all experimental protocols was approved by the Special Committee on Scientific Ethics of Ocean University of China (OUC-HM-2021-012). We confirm that all methods were carried out in accordance with Observational studies (STROBE) guidelines. Prior to participating in the study, all participants's parents were informed of the study purpose and details of the study procedure and were requested to give their informed consent.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author (Shiming. Li) on reasonable request. The data sets are not publicly available due to restrictions imposed by Ocean University of China Review Board (OUC-HM-2021-012).

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

R.L and S.L (Shuoqi.Li) wrote the main manuscript text and Rong.Guo prepared figures. T.Y, Z.D and X.Z completed the experiment and data collection.T.H, S.L (Shiming.Li) and W.Y designed the experiment and revised the manuscript. All authors reviewed the manuscript.

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Figures

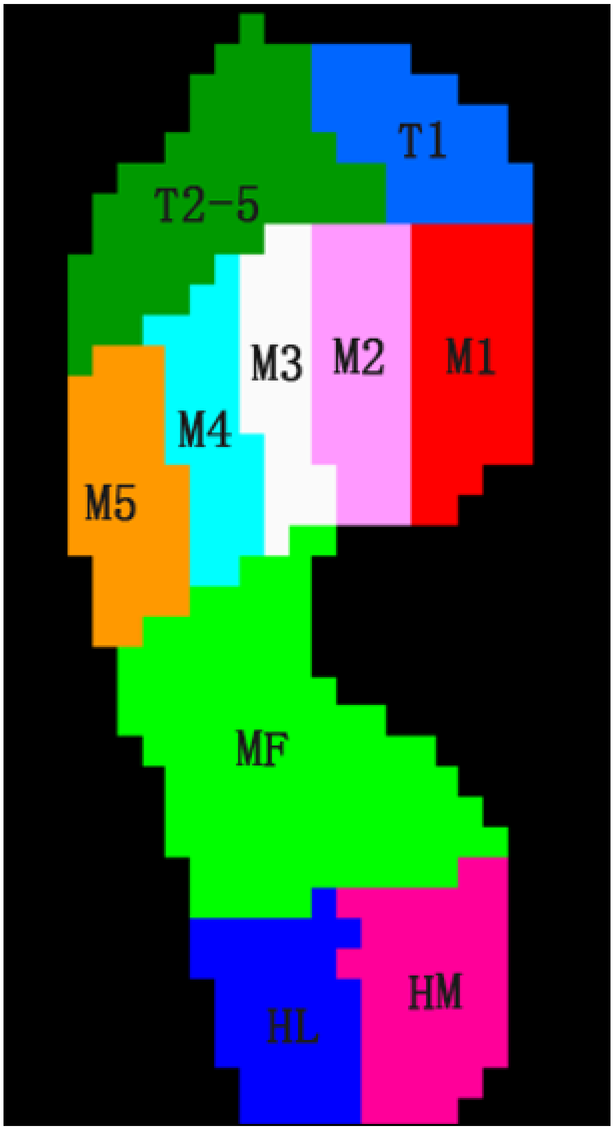

Figure 1

The 10 anatomical masking areas

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- AppendixA.docx
- AppendixB.docx
- AppendixC.tiff