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ENHANCED ACTIVE CONTRACTION OF THE TRANSVERSUS ABDOMINIS DURING WALKING

AUMENTO DA CONTRAÇÃO ATIVA DO MÚSCULO TRANSVERSO DO ABDOME DURANTE A CAMINHADA

AUMENTO DE LA CONTRACCIÓN ACTIVA DEL MÚSCULO TRANSVERSO DEL ABDOMEN DURANTE LA CAMINATA

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ABSTRACT

Introduction: We applied three-dimensional gait analysis to assess the effects of enhanced active contraction of the transversus abdominis (EACTA) during walking. We sought to evaluate the effect of EACTA during walking in order to improve walking quality. Methods: Thirty college students were recruited and trained to perform EACTA during walking. We examined gait parameters under different conditions, including EACTA and habitual ACTA (natural walking with mild contraction of the feedforward mechanism of ACTA, HACTA) during walking using three-dimensional gait analysis. We compared differences in gait parameters under the two walking conditions using SPSS 16.0 statistical software. Results: The following gait parameters were significantly lower under EACTA conditions than under HACTA conditions (P < 0.05): stance phase, 59.151% ± 1.903% vs. 59.825% ± 1.495%; stride time, 1.104 s ± 0.080 s vs. 1.134 s ± 0.073 s:; stance time, 0.656 s ± 0.057 s vs. 0.678 s ± 0.053 s; and swing time, 0.447 s ± 0.028 s vs. 0.454 s ± 0.031 s, respectively. Gait parameters single support phase and mean velocity were significantly higher for EACTA than for HACTA conditions (both P < 0.05). Conclusions: Overall, the results revealed that EACTA during walking can improve gait. This method is simple, and EACTA training during walking to improve gait quality in daily life could provide a positive basis for people to strengthen the transverse abdominal muscle. ***Level of evidence III; Retrospective comparative study.***

Keywords: Walking; Transversus abdominis; Muscle contraction; Gait analysis.

RESUMO

Introdução: Aplicamos a análise tridimensional da marcha para avaliar os efeitos do aumento da contração ativa do músculo transverso do abdome (EACTA) durante a caminhada. Procuramos avaliar o efeito do EACTA durante a caminhada para melhorar sua qualidade. Métodos: Trinta estudantes universitários foram recrutados e treinados para realizar o EACTA durante a caminhada. Examinamos os parâmetros da marcha em diferentes condições, incluindo EACTA e ACTA habitual (caminhada natural com leve contração do mecanismo de feedforward *do ACTA, HACTA) durante a caminhada usando análise tridimensional da marcha. Comparamos as diferenças nos parâmetros da marcha nas duas condições de caminhada no software estatístico SPSS 16.0. Resultados: Os seguintes parâmetros da marcha foram significativamente mais baixos na condição EACTA do que em condições HACTA (P < 0,05): fase de apoio 59,151 ± 1,903% vs. 59,825 ± 1,495%, tempo de passada 1,104 s ± 0,080 s vs. 1,134 s ± 0,073 s, tempo de apoio 0,656 s ± 0,057 s vs. 0,678 s ± 0,053 s e tempo de balanço 0,447 s ± 0,028 s vs. 0,454 s ± 0,031 s, respectivamente. Os parâmetros da marcha fase de apoio simples e velocidade média foram significativamente maiores no EACTA do que nas condições HACTA (ambos P < 0,05). Conclusões: No geral, os resultados revelaram que o EACTA durante a caminhada pode melhorar a marcha. Esse método é simples, e o treinamento do EACTA durante a caminhada para melhorar a qualidade da marcha na vida diária pode ser uma base positiva para o fortalecimento do músculo transverso do abdome.* ***Nível de evidência III; Estudo retrospectivo comparativo.***

Descritores: *Caminhada; Músculos abdominais; Contração muscular; Análise da marcha.*

RESUMEN

Introducción: Aplicamos el análisis tridimensional de la marcha para evaluar los efectos del aumento de la contracción activa del músculo transverso del abdomen (EACTA) durante la caminata. Buscamos evaluar el efecto del EACTA durante la caminata para mejorar su calidad. Métodos: Treinta estudiantes universitarios fueron reclutados y entrenados para realizar el EACTA durante la caminata. Examinamos los parámetros de la marcha en diferentes condiciones, incluyendo EACTA y ACTA habitual (caminata natural con leve contracción del mecanismo de feedforward *del ACTA, HACTA) durante la caminata usando análisis tridimensional de la marcha. Comparamos las diferencias en los parámetros de la marcha en las dos condiciones de caminata en el software estadístico SPSS 16.0. Resultados: Los siguientes parámetros de marcha fueron significativamente más bajos en la condición EACTA que en condiciones HACTA (P <0,05): fase de apoyo 59,151 ± 1,903% vs 59,825 ± 1,495%, tiempo de zancada 1,104 s ± 0,080 s vs 1,134 s ± 0,073 s, tiempo de apoyo 0,656 s ± 0,057 s vs 0,678 s ± 0,053 s y tiempo de balance 0,447 s ± 0,028 s vs 0,454 s ± 0,031 s, respectivamente. Los parámetros de la marcha, fase de apoyo simple y velocidad promedio fueron significativamente mayores en el EACTA que en las condiciones HACTA (ambos P <0,05). Conclusiones:*

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En general, los resultados revelaron que el EACTA durante la caminata puede mejorar la marcha. Este método es simple, y el entrenamiento del EACTA durante la caminata para mejorar la calidad de la marcha en la vida diaria puede ser una base positiva para el fortalecimiento del músculo transverso del abdomen. ***Nivel de evidencia III; Estudio retrospectivo comparativo.***

Descriptores: *Caminata; Músculos abdominales; Contracción muscular; Análisis de la marcha.*

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INTRODUCTION

Walking is important for daily living in humans. Walking can affect many functions of the human body,[1-2] and individuals' walking ability is directly related to their independence in daily life. Previous studies have reported that improving gait is an important method for improving quality of life.[3-4] Human walking involves the coordinated movement of the muscles and joints of the foot, ankle, knee, hip, trunk, shoulder and neck. Previous studies have reported that patients with spinal degenerative diseases (e.g., cervical spondylosis, lumbar disc herniation, and non-specific low back pain resulting in lower limb pain, and paresthesia because of spinal nerve or spinal cord compression) exhibit abnormal gait, which may improve after treatment.[5] These findings indicate that the stability of the spine plays an important role in walking.

The transverse abdominal muscle (TrA) is located deep within the internal oblique abdomen, originating in the iliac crest, thoracolumbar fascia, ribs 6–12, and the inguinal ligament, inserting into the linea alba and contralateral rectus abdominis sheath.[6-7] Thus, the TrA is the most important muscle for maintaining spinal stability,[8-9] and is an important component of the core muscle group. The TrA plays an important role in maintaining the stability of the spine during dynamic and static activities,[10-14] and can contribute to the improvement of gait.[15] Therefore, strengthening the active contraction of the TrA during walking may improve the quality of walking, with potential positive effects for preventing and treating abnormal gait, joint and spinal pain.

Previous clinical studies have reported that walking speed, cycle, stance phase and step length improve after TrA muscle training in stroke and cerebral palsy patients.[16,17] In addition, some gait parameters have been reported to improve after trunk movement in water (including training of core muscle groups such as TrA) with hemiplegic stroke patients.[18] At present, although a number of previous studies have reported the effects of transverse abdominal muscle training (TAMT) on gait changes, the experiments have typically been divided into two steps: patients first undergo TAMT guided by researchers, then changes of gait parameters are examined after TAMT. However, no previous studies have examined the effects of enhanced transversus abdominis active contraction (ETAAC) on gait state during walking.

During walking, individuals exhibit slight TrA active contraction (TAAC) most of the time, through a forward feedback mechanism in habitual or "normal" daily gait. Thus, individuals do not typically focus on the importance of strengthening TrA contraction during walking, potentially resulting in abnormal gait that an individual may consider to be normal. However, such "normal" gait may lead to biomechanical changes in the long term, potentially resulting in lower extremity joint pain and spinal pain. Therefore, strengthening the active contraction of the TrA during walking can improve walking quality, and may have positive effects for preventing and treating abnormal gait, joint pain, and spinal pain.

According to functional anatomy of TrA and present evidence, we found that different degrees of TAAC can impact on human gait. Thus, we applied three-dimensional gait analysis to compare the difference of gait parameters between enhanced TAAC (ETAAC) and habitual TAAC (HTAAC) during walking, and compared the differences of gait parameters under the two walking conditions in college students. We then analyzed defects in "normal" walking, and examined the effects of ETAAC on walking quality. The results support the application of abdominal transverse muscle isotonic training to improve gait in daily life in healthy individuals.

METHODS

Participants

We recruited 30 participants. The inclusion criteria were as follows: college students with normal exercise routines; ability to complete all testing procedures according to instructions. The exclusion criteria were as follows: presence of other serious diseases of the system or organs; inability to complete the test. The study was approved by Ethics Committee of The Fifth Affiliated Hospital of Guangzhou Medicine University (KY01-2019-04-04). All patients provided written informed consent.

Participants' basic information collection and gait pre-test data measurement

We collected basic personal information from participants as required by the gait data analysis system, including: age, sex, height, weight, left malleolus width, right malleolus width, left knee diameter, and right knee diameter, left leg length and right leg length, left pelvis depth, right pelvis depth, and anterior superior iliac spine breadth. (Figure 1)

Determining participants' walking parameters in the HTAAC walking state

Participants were familiarized with the gait analysis test flow and equipment operation. A fluorescent ball was attached to the body surface, (Figure 2) and the researcher avoided subjective psychological interference of the participants. To maintain natural gait movement, participants were instructed to avoid excessively attending to or deliberately adjusting their gait.

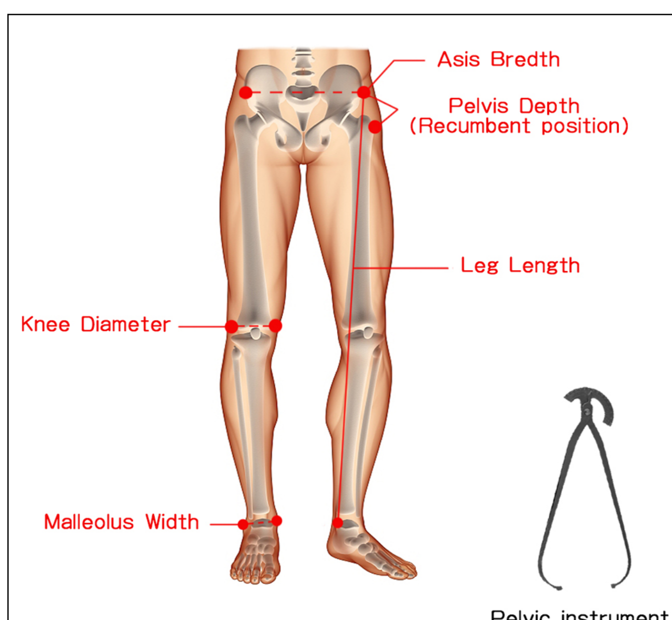

Figure 1. The basic measurement of gait analysis.

Participants stood at the center of the force table for at least 5 s and the values of each parameter were measured while the participant remained still. The participants walked back and forth six times on an 8-m-long monitoring platform in accord with their natural style of walking in daily life, while the computer system performed 3D imaging. The walking parameters included: stride length (m), step length (m), stride speed (m/s), cadence (steps/min), step width (m), stance phase (%), swing phase (%), double support phase (%), single support phase (%), hip rotation (degree), hip ab-adduction (degree), hip flex-extension (degree), pelvic rotation (degree), pelvic ab-adduction (degree), pelvic flex-extension (degree), knee rotation (degree), ankle dorsi-plantarflex (degree), mean velocity (m/s), mean velocity (%height/s), stride length (%height), foot progression (degree), stride time (s), stance time (s), swing time (s), gait profile score (degree), and gait deviation index. To avoid interference with participants' normal gait, researchers gave no other instructions or prompts during the imaging progress.

Guiding participants to walk under the ETAAC

Teaching and guidance of ETAAC were given during walking in the ETAAC condition. Participants were instructed in ETAAC while maintaining natural breathing. Participants were told to touch their abdomen with their hands when walking in this state, until they experienced a stronger feeling of deep muscle activity than during natural walking. (Figure 3) When participants were skilled in walking in this state, they were asked to walk in accord with their natural state, but with the inclusion of ETAAC, and walking parameters were measured. (Figure 4)

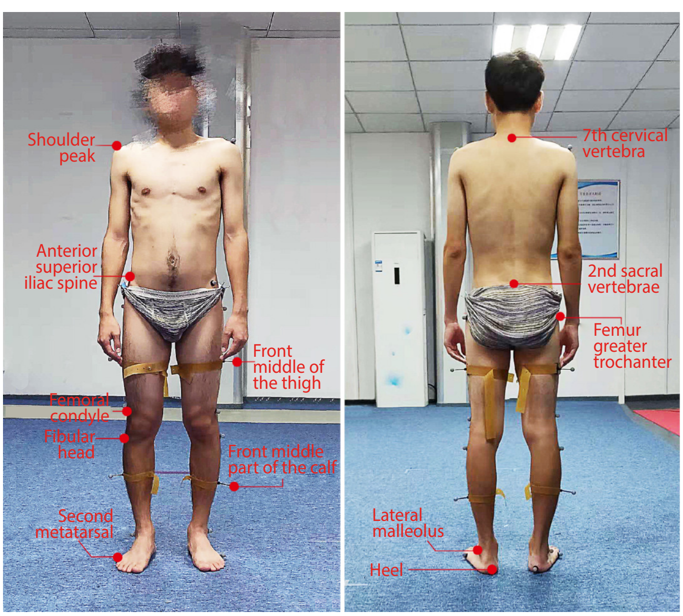

Figure 2. The position of the fluorescence sphere.

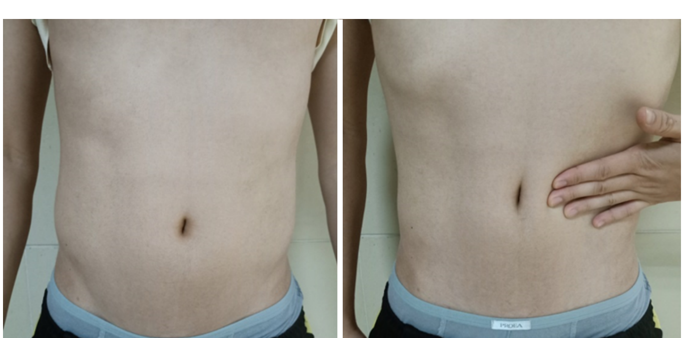

Figure 3. The participant touched their own abdominal area to feel the muscle contraction state in the HTAAC and ETAAC conditions before gait parameter analysis (A: HTAAC, B: ETAAC).

The method for measuring gait parameters was the same as that for natural walking. To prevent data errors, participants were asked whether they breathed normally and maintained abdominal contraction during the whole course, after each gait cycle.

Statistical Analysis

Paired t-tests were performed on the two states of each observation. Analysis was performed using SPSS 17.0 software (Chicago, USA), with a significance level of $\alpha = 0.05$.

RESULTS

Participants' characteristics

According to the inclusion and exclusion criteria, a total of 30 eligible college students participated in the study, including 15 men and 15 women. Participants' age, height, weight, width of the left ankle and right ankle, diameter of the left knee and right knee, length of the left leg and right leg, width of the left pelvis and right pelvis, length of two anterior superior iliac spine, and the walking measurement parameters are shown in Table 1.

Comparison of walking parameters in different contraction states of the transverse abdominis muscle

The stance phase, double support phase, stride time, stance time, and swing time were significantly lower in the ETAAC condition than in HTAAC condition, and the single support phase, mean velocity y(m/s), and mean velocity (%height/s) were significantly higher in the ETAAC than the HTAAC condition. All of the above parameters exhibited significant differences ($P < 0.05$). However, some parameters, including stride length, step length, cadence (steps/min), step width (m) in the ETAAC condition were increased compared with the HTAAC condition, and the P-values for step length and cadence (steps/min) almost reached 0.05, indicating possible differences. (Table 2)

DISCUSSION

Walking is a basic motor function of the human body in daily living,[19] and high-quality walking function involves a high level of coordination of multiple body parts. Particularly for older individuals, improving walking quality can save energy,[20-22] reduce joint load, and prevent the risk of falling during walking.

Previous studies have reported that walking quality is closely related to spinal stability,[23] and the TrA is important for spine stabilization.[10-14] In addition, during physical movement, the TrA is activated by a feed-forward mechanism to stabilize the lumbar spine and pelvis.[11] In clinical practice, some previous studies have reported that the TrA is vital for core stability during exercises involving the contraction of core muscles.[24-26] Although the current study separated training between walking and TrA contraction, we plan to investigate the effect of active TrA contraction on walking in future studies, by linking both conditions (walking and ETAAC).

Clinically, three-dimensional gait analysis is considered the gold standard to quantify lower limb movements and its reliability was excellent.[27] By capturing motion data for each joint during walking and calculating parameters such as walking cycle, speed, stride length, step length and foot deviation angle, it is possible to examine the muscle, joint function and coordination related to walking.[28] A walking cycle consists of two parts: the stance phase and the swing phase, where the stance phase accounts for approximately 60% of the cycle, and the swing phase accounts for approximately 40%. The single support phase takes up a large proportion of the walking cycle, while the rest of the cycle is dedicated to the double support phase, which is inversely proportional to the walking speed.[29] It should be noted that when obstacles are encountered

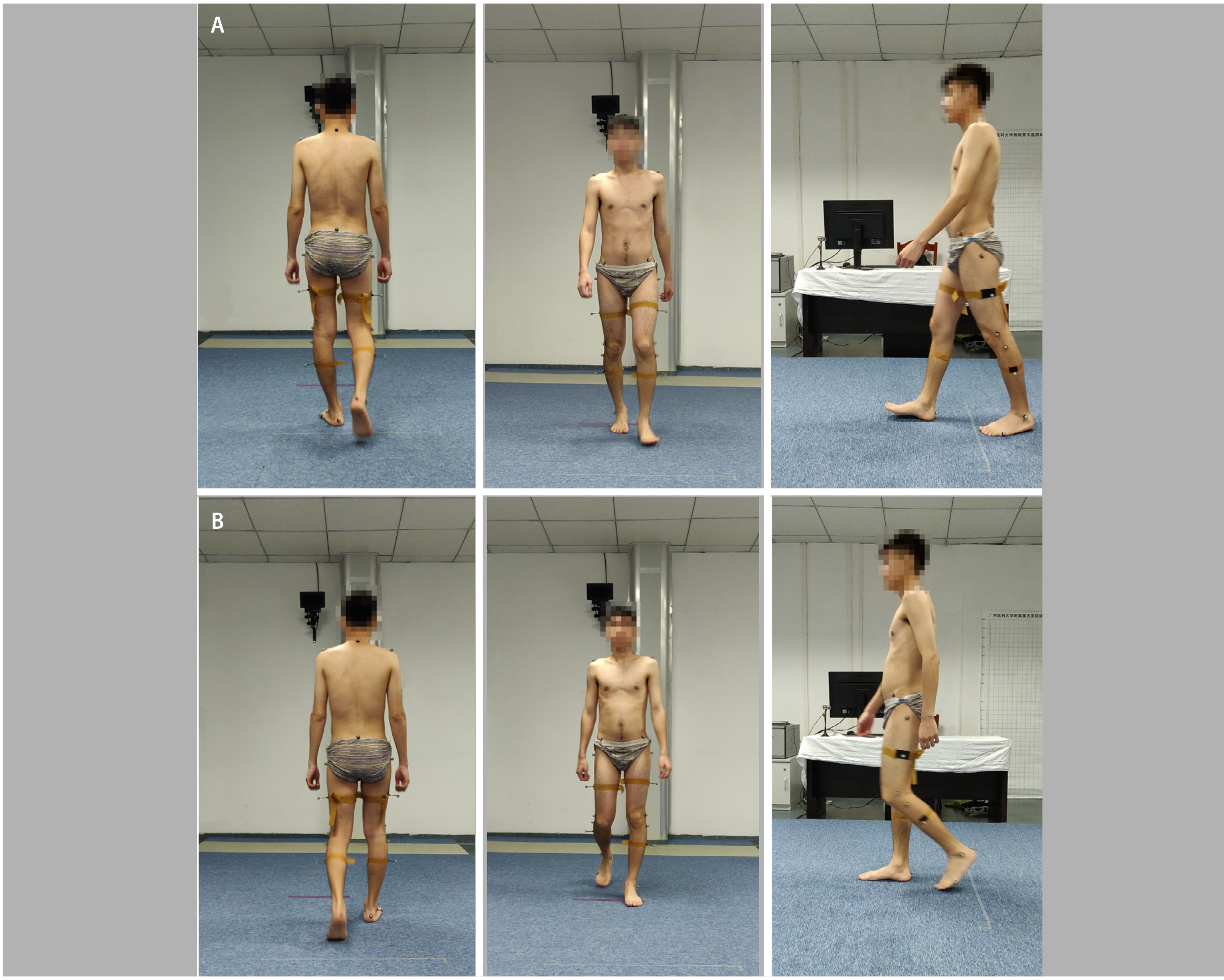

Figure 4. Three views in the ETAAC (A) and HTAAC (B) conditions.

Table 1. Participants' basic information.

Name of basis condition	(mean±SD)
Male (15) age (y)	20.87±0.88
Female age (y)	20.87±2.00
Height (m)	165.28±8.78
Weight (Kg)	54.77±9.69
Width of left ankle (cm)	7.96±1.13
Width of right ankle (cm)	7.93±1.15
Diameter of left knee (cm)	10.90±1.04
Diameter of right knee (cm)	10.92±1.06
Long of left leg (cm)	82.35±4.97
Long of right knee (cm)	8.22±4.80
Width of left pelvic (cm)	10.34±1.30
Width of right pelvic (cm)	11.15±2.48
Distance of two anterior superior iliac spine (cm)	24.83±1.68

during walking, the duration of the double support phase extends to improve the walking stability. Moreover, the stance phase is related to the stability of walking.[30-31] In the current study, we observed changes of gait parameters of healthy individuals under ETAAC conditions during walking. The results revealed that, in the walking cycle, the percentage of stance phase in the ETAAC condition (59.151 ± 1.903)% was significantly lower than in the HTAAC condition (59.825 ± 1.495)% ($P < 0.05$), while the percentage of single support phase in the ETAAC condition (40.726 ± 1.808)% was significantly higher than in the HTAAC condition (39.986 ± 1.250)% ($P < 0.05$). We found that the double support phase time was also lower in the ETAAC condition than in the HTAAC condition (39.986 ± 1.250)% ($P < 0.05$). Although the difference in this parameter did not reach significance in either condition, the P-values were close to 0.05. (Table 2) This result suggests that walking in the ETAAC condition increased walking speed. Previous studies reported that high walking speed is important for daily living and social participation ability,[32] and that walking quality includes the ability to walk quickly.[33] Some walking training methods aim to improve walking speed.[34] Taken together, these findings suggest that walking under ETAAC conditions could improve walking quality and facilitate walking in daily living.

During the trial, participants were required to strengthen and contract the TrA while walking. Most individuals accustomed to walking in a natural state become breathless when first performing TrA while walking. Therefore, it is important to conduct static lower TrA contraction training. Currently, the abdominal hollowing exercise (AHE) is commonly used to train the TrA. In this exercise, patients lie on their back, bend their hips and knees, step on the bed with both feet flat on the bed, then perform abdominal contraction. The navel is tightened toward the back and close to the spine. Success is indicated by the ability to selectively activate the TrA rather than the superficial muscles, including the internal oblique, external oblique, or rectus abdominis muscles. Some researchers have used biofeedback techniques to assist in the activation of the TrA,[35-36]

Table 2. Comparison of gait parameters in ETAAC and HTAAC conditions during walking.

Gait parameters	HTAAC	ETAAC	T value	P value
Stride length(m)	1.187±0.091	1.195±0.098	-0.707	0.485
Step length(m)	0.581±0.086	0.597±0.063	-1.799	0.082
Cadence(steps/min)	105.32±11.181	109.08±18.794	-1.797	0.083
Step width(m)	0.087±0.028	0.090±0.039	-0.422	0.676
Stance phase (%)	59.825±1.495	59.151±1.903	2.077	0.047
Single support phase (%)	39.986±1.250	40.726±1.808	-2.750	0.010
Double support phase (%)	9.987±1.413	9.483±1.501	1.765	0.088
Pelvic obliquity (degree)	2.377±0.994	2.297±0.959	0.851	0.402
Pelvic tilt (degree)	4.567±4.255	4.760±4.437	-0.809	0.425
Pelvic rotation (degree)	3.600±1.460	3.810±1.428	-1.372	0.181
Hip ab-adduction (degree)	3.193±1.669	3.550±1.923	-1.380	0.178
Hip flex-extension (degree)	7.773±5.319	7.930±5.563	-0.654	0.518
Hip rotation (degree)	14.817±11.599	13.543±8.414	1.068	0.294
Knee flex-extension (deg)	10.027±3.028	9.943±3.222	0.311	0.758
Ankle dorsi-plantarflex (deg)	7.243±2.440	7.380±2.564	-0.530	0.600
Mean velocity (m/s)	1.050±0.107	1.104±0.143	-2.732	0.011
Mean velocity (%height/s)	68.269±23.234	71.056±26.158	-2.344	0.026
Stride length ((%height)	77.155±29.053	78.030±29.663	-1.309	0.201
Foot progression (degree)	5.153±3.166	5.667±4.746	-0.973	0.339
Stride time (s)	1.134±0.073	1.104±0.080	3.075	0.005
Stance time (s)	0.678±0.053	0.656±0.057	2.881	0.007
Swing time (s)	0.454±0.031	0.447±0.028	2.124	0.042
Gait profile score (degree)	7.948±2.430	7.997±2.480	-0.603	0.551
Gait deviation index	92.221±8.608	92.174±8.685	0.140	0.889

ETAAC: enhancing transversus abdominis active contraction; HTAAC: habitual transversus abdominis active contraction (natural mildly contraction of the forward feedback mechanism of TAAC).

including the use of real-time ultrasound imaging to provide feedback about contraction of the TrA. Some have attempted to use electromyography to distinguish individual muscle contractions by measuring signals from different muscles. However, neither of these techniques is able to determine whether the TrA is correctly contracted during specific functional training.[37] And the results of electromyography may not be accurate because the TrA is located in the deep muscle layers, and is subject to interference from the signals of adjacent muscle contractions. In addition, because the purpose of the current study was to explore the effects of active contraction of the TrA on gait in daily life, it was easier to use an accurate visual demonstration and instructions in daily life. Therefore, we used a visual demonstration and instructions to prompt participants to perform the exercise correctly. In addition, we instructed participants to palpate their contracting muscles with the fingers so that they could experience sensory information associated with muscle contraction, and accurately judge whether their muscles were contracting. (Figure 2) We found that TrA active contraction changed participants' gait, playing an important role in improving walking quality. The results suggested that this mode of walking is more conducive to the stability of the trunk. Thus, the current study further clarified the positive effects of strengthening active contraction of the TrA in daily walking.

Because natural walking involves habitual TAAC via a forward feedback mechanism most of the time, people do not typically pay attention to the importance of ETAAC during walking. This can lead individuals to walk in an unsynchronized state over a long period. This situation can cause biomechanical changes, which may lead to pain in the lower extremity joints, increasing the risk of falls.[38] Normalizing ETAAC could provide a practical technique for active prevention and rehabilitation of uncomfortable gait abnormalities and patients with walking abnormalities due to illness. Through training, the stability of the spine can be further improved, lumbosacral pain caused by aging can be prevented, and the risk of falling caused by decreased balance coordination ability during walking can be reduced, potentially reducing lumbosacral pain. Ultimately, this could reduce the incidence of lumbosacral pain and falling, and could reduce the associated use of medical resources, with substantial economic and social benefits.

However, this study was only carried out in healthy college students, and the sample size of the study was relatively small. Therefore, the effects of walking combined with active enhancement of TrA contraction on gait function and the impact of different populations requires further study. In future, we hope that exercise programs will be developed for healthy individuals to encourage continuous or regular interval TrA contraction, to improve the quality of walking.

CONCLUSIONS

Taken together, our findings suggested that ETAAC during walking can improve gait. This method is simple, and ETAAC training during walking for improving the quality of walking could provide a positive basis for people to strengthen the transverse abdominal muscle training in daily life. But we need to further investigate the walking posture in different people in the future.

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REFERENCES

1. Hamid A, Sahar J, Nurviyandari D. Walking and talking activities as nursing therapy for improving quality of life among older adults. Enferm Clin. 2018;28(Suppl 1):61-5.
2. Murtagh EM, Nichols L, Mohammed MA, Holder R, Nevill AM, Murphy MH. The effect of walking on risk factors for cardiovascular disease: an updated systematic review and meta-analysis of randomised control trials. Prev Med. 2015;72:34-43.
3. Polese JC, Teixeira-Salmela LF, Nascimento LR, Faria CDM, Kirkwood RN, Laurentino GC, et al. The effects of walking sticks on gait kinematics and kinetics with chronic stroke survivors. Clin Biomech (Bristol, Avon). 2012;27(2):131-7.
4. Cruz-Jimenez M. Normal Changes in Gait and Mobility Problems in the Elderly. Phys Med Rehabil Clin N Am. 2017;28(4):713-25.
5. Simon AL, Lugade V, Bernhardt K, Larson NA. Kaufman K. Assessment of stability during gait in patients with spinal deformity-A preliminary analysis using the dynamic stability margin. Gait Posture. 2017;55:37-42.
6. O'Sullivan P, Twomey L, Allison G, Sinclair J, Miller K. Altered patterns of abdominal muscle activation in patients with chronic low back pain. Aust J Physiother. 1997;43(2):91-8.
7. O'Sullivan PB, Phyty GD, Twomey LT, Allison GT. Evaluation of specific stabilizing exercise in the treatment of chronic low back pain with radiologic diagnosis of spondylolysis or spondylolisthesis. Spine (Phila Pa 1976). 1997;22(24):2959-67.
8. Baek SO, Ahn SH, Jones R, Cho HK, Jung GS, Cho YW, et al. Activations of Deep Lumbar Stabilizing Muscles by Transcutaneous Neuromuscular Electrical Stimulation of Lumbar Paraspinal Regions. Ann Rehabil Med. 2014;38(4):506-13.
9. MacKenzie JF, Grimshaw PN, Jones CDS, Thoirs K, Petkov J. Muscle activity during lifting: examining the effect of core conditioning of multifidus and transversus abdominis. Work. 2014;47(4):453-62.
10. Crommert ME, Ekblom MM, Thorstensson A. Activation of transversus abdominis varies with postural demand in standing. Gait Posture. 2011;33(3):473-7.
11. Hodges PW, Richardson CA. Delayed postural contraction of transversus abdominis in low back pain associated with movement of the lower limb. J Spinal Disord. 1998;11(1):46-56.

12. Tsang SMH, Lam AHM, Ng MHL, Ng KWK, Tsui COH, You B. Abdominal muscle recruitment and its effect on the activity level of the hip and posterior thigh muscles during therapeutic exercises of the hip joint. J Electromyogr Kinesiol. 2018;42:10-9.
13. Ehsani F, Arab AM, Jaberzadeh S, Salavati M. Ultrasound measurement of deep and superficial abdominal muscles thickness during standing postural tasks in participants with and without chronic low back pain. Man Ther. 2016;23:98-105.
14. Chon SC, Chang KY, You JS. Effect of the abdominal draw-in manoeuvre in combination with ankle dorsiflexion in strengthening the transverse abdominal muscle in healthy young adults: a preliminary, randomised, controlled study. Physiotherapy. 2010;96(2):130-6.
15. Gnat R, Spoor K, Pool-Goudzwaard A. The influence of simulated transversus abdominis muscle force on sacroiliac joint flexibility during asymmetric moment application to the pelvis. Clin Biomech (Bristol, Avon). 2015;30(8):827-31.
16. Sharma Vishal, Kaur Jaskirat. Effect of core strengthening with pelvic proprioceptive neuromuscular facilitation on trunk, balance, gait, and function in chronic stroke. 2017;13(2):200-5.
17. Haruyama K, Kawakami M, Otsuka T. Effect of Core Stability Training on Trunk Function, Standing Balance, and Mobility in Stroke Patients. Neurorehabil Neural Repair. 2017;31(3):240-9.
18. Park BS, Noh JW, Kim MY, Lee LK, Yang SM, Lee WD, et al. The effects of aquatic trunk exercise on gait and muscle activity in stroke patients: a randomized controlled pilot study. J Phys Ther Sci. 2015;27(11):3549-53.
19. Kim GY, Han MR, Lee HG. Effect of Dual-task Rehabilitative Training on Cognitive and Motor Function of Stroke Patients. J Phys Ther Sci. 2014;26(1):1-6.
20. VanSwearingen JM, Perera S, Brach JS, Cham R, Rosano C, Studenski AS. A randomized trial of two forms of therapeutic activity to improve walking: effect on the energy cost of walking. J Gerontol A Biol Sci Med Sci. 2009;64(11):1190-8.
21. Silva RB, Eslick GD, Duque G. Exercise for falls and fracture prevention in long term care facilities: A systematic review and meta-analysis. J Am Med Dir Assoc. 2013;14(9):685–89.
22. Brach JS, Van Swearingen JM, Perera S, Wert DM, Studenski S. Motor learning versus standard walking exercise in older adults with subclinical gait dysfunction: a randomized clinical trial. J Am Geriatr Soc. 2013;61(11):1879-86.
23. Ghamkhar L, Kahlaee AH. Trunk Muscles Activation Pattern During Walking in Subjects With and Without Chronic Low Back Pain: A Systematic Review. 2015;7(5):519-26.
24. Hodges PW, Richardson CA. Feedforward contraction of transversus abdominis is not influenced by the direction of arm movement. Exp Brain Res. 1997;114(2):362-70.
25. Hodges PW, Richardson CA. Contraction of the abdominal muscles associated with movement of the lower limb. Phys Ther. 1997;77(2):132-42.
26. Hodges PW, Richardson CA. Inefficient muscular stabilization of the lumbar spine associated with low back pain. A motor control evaluation of transversus abdominis. Spine (Phila Pa 1976). 1996;21(22):2640-50.
27. Pantzar-Castilla E, Cereatti A, Figari G, Valeri N, Paolini G, Croce UD, et al. Knee joint sagittal plane movement in cerebral palsy: a comparative study of 2-dimensional markerless video and 3-dimensional gait analysis. 2018;89(6):656-61.
28. Kim CR, Yoo JY, Lee SH, Lee DH, Rhim SC. Gait analysis for evaluating the relationship between increased signal intensity on t2-weighted magnetic resonance imaging and gait function in cervical spondylotic myelopathy. Arch Phys Med Rehabil. 2010;91(10):1587-92.
29. Rabin E, Shi P, Werner W. Gait parameter control timing with dynamic manual contact or visual cues. J Neurophysiol. 2016;115(6):2880-92.
30. Orcioli-Silva D, Barbieri FA, Simieli L, Vitorio R, Santos PCR, Beretta VS, et al. Walking behavior over multiple obstacles in people with Parkinson's disease. Gait Posture. 2017;58:510-5.
31. Orcioli-Silva D, Vitório R, Lirani-Silva E, Santos PCR, Beretta VS, Gobbi LTB, et al. Objective measures of unobstructed walking and obstacle avoidance in Parkinson's disease subtypes. Gait Posture. 2018;62:405-8.
32. Pramodhyakul N, Amatachaya P, Sooknuan T, Arayawichanon P, Amatachaya S. Effects of a visuotemporal cue on walking ability of independent ambulatory subjects with spinal cord injury as compared with healthy subjects. Spinal Cord. 2014;52(3):220-4.
33. Aguirre-Güemez AV, Pérez-Sanpablo AI, Quinzaños-Fresnedo J, Pérez-Zavala R, Barrera-Ortiz A. Walking speed is not the best outcome to evaluate the effect of robotic assisted gait training in people with motor incomplete Spinal Cord Injury: A Systematic Review with meta-analysis. J Spinal Cord Med. 2019;42(2):142-54.
34. Rodrigues-Baroni JM, Nascimento LR, Ada L, Teixeira-Salmela LF. Walking training associated with virtual reality-based training increases walking speed of individuals with chronic stroke: systematic review with meta-analysis. Braz J Phys Ther. 2014;18(6):502-12.
35. Teyhen DS, Miltenberger CE, Deiters HM, Del Toro YM, Pulliam JN, Childs JD, et al. The use of ultrasound imaging of the abdominal drawing-in maneuver in subjects with low back pain. J Orthop Sports Phys Ther. 2005;35(6):346-55.
36. Hodges P, Richardson C, Jull G. Evaluation of the relationship between laboratory and clinical tests of transversus abdominis function. Physiother Res Int. 1996;1(1):30-40.
37. Henry SM, Westervelt KC. The use of real-time ultrasound feedback in teaching abdominal hollowing exercises to healthy subjects. J Orthop Sports Phys Ther. 2005;35(6):338-45.
38. Khan SJ, Khan SS, Usman J. The effects of toe-out and toe-in postures on static & dynamic balance, risk of fall and TUG score in healthy adults. Foot (Edinb). 2019;39:122-8.