Applied Animal Behaviour Science 135 (2011) 271–276

Contents lists available at SciVerse ScienceDirect

Applied Animal Behaviour Science

journal homepage: www.elsevier.com/locate/applanim

Three-dimensional analysis of horse and human gaits in therapeutic riding

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A R T I C L E I N F O

Article history:
Accepted 26 October 2011

Keywords:
Equine-facilitated interventions
Horse gait
Human gait
Three-dimensional analysis
Horse riding

A B S T R A C T

Therapeutic horse riding or hippotherapy is used as an intervention for treating individuals with mental and physical disabilities. Equine-assisted interventions are based on the hypothesis that the movement of the horse's pelvis during horseback riding resembles human ambulation, and thus provides motor and sensory inputs similar to those received during human walking. However, this hypothesis has not been investigated quantitatively and qualitatively. This study aimed to verify the hypothesis by conducting a three-dimensional analysis of the horse's movements while walking and human ambulation. Using four sets of equipments, we analysed the acceleration patterns of walking in 50 healthy humans and 11 horses. In addition, we analysed the exercise intensity by comparing the heart rate, breathing rate, and blood pressure of 127 healthy individuals before and after walking and horse riding. The acceleration data series of the stride phase of horse walking were compared with those of human walking, and the frequencies (in Hz) were analysed by Fast Fourier transform.

The acceleration curves of human walking overlapped with those of horse walking, with the frequency band of human walking corresponding with that of horse walking. Exercise intensity, as measured by the heart rate and breathing rate, was not significantly different between horse riding and human walking. The levels of diastolic blood pressure were slightly higher during horse riding than during walking, but were lower during both conditions compared with those in normal conditions ($P < 0.01$). The present study shows that, although not completely matched, the accelerations of the horse and human walking are comparable quantitatively and qualitatively. Horse riding at a walking gait could generate motor and sensory inputs similar to those produced by human walking, and thus could provide optimum benefits to persons with ambulatory difficulties.

1. Introduction

Equine-assisted therapeutic interventions are used in many institutions worldwide for the treatment of individuals with mental and physical disabilities. Therapeutic horse riding or hippotherapy is often employed in the physiotherapy of children with cerebral palsy (Shurtleff et al., 2009; Sterba, 2007) and patients with spinal cord injury (Lechner et al., 2003) and multiple sclerosis (Hammer et al., 2005). Although many reports have demonstrated the therapeutic benefits of horse riding, the underlying mechanisms have not been elucidated. The lack of scientific approaches in the study of therapeutic riding may be a major obstacle to the development of hippotherapy and/or therapeutic horse riding (Potter et al., 1994).

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0168-1591/$ – see front matter
doi:10.1016/j.applanim.2011.10.024

The movement of the horse's pelvis during horseback riding provides motor and sensory inputs to the human body. The reciprocal movement of the walking horse produces pelvic movement in the rider's body that closely resembles human ambulation (Bertoti, 1988; Fleck, 1992; Potter et al., 1994). This implies that the horse's pelvic movement is similar to the human pelvic movement while walking. Later studies that investigated the therapeutic effects of horseback riding on children with cerebral palsy were premised on the same hypothesis (McGibbon et al., 1998; Sterba et al., 2002). However, this hypothesis has not been verified by quantitative and qualitative analyses.

This study aimed to investigate the hypothesis that the stimulation received from the horse's gait resembles the stimulation produced by human walking. Accelerometry offers a practical method to objectively monitor movements in humans (Mathie et al., 2004) and animals (Robert et al., 2009; Scheibe and Gromann, 2006), including horses (Barrey, 1999; Matsuura et al., 2008). We used this method to analyse the three-dimensional acceleration of horse and human gaits. Acceleration results in changes in gravity, generating physical stimuli to the rider's body. The similarity between the accelerations of the horse and human gaits indicates that horse riding could provide the motor input received from walking, and thus can be used as a treatment intervention for persons with ambulatory difficulties.

2. Materials and methods

All the experiments in this study were approved by the Animal Experiment Ethics Committee of Azabu University (080618-1).

Fifty healthy individuals (21 men and 29 women; age, 20–24 years) participated in this study. We used 11 horses (age, 10–24 years) of the following breeds: thoroughbred (TH; $n = 3$, all geldings), Kiso ($n = 1$, gelding), Hokkaido (HK; $n = 1$, gelding), Selle Francais (SF; $n = 1$, mare), criollos (CRI; $n = 2$, both geldings), and half-breed (HB; $n = 3$, all mares) (Table 1). The horses were healthy and did not have claudication symptoms. The HK breed had an amble gait, whereas the other horse breeds had a diagonal gait. We also measured the stride length (cm) and gait speed (m/s) of the horses (Table 1).

Using four sets of equipment to measure three-dimensional acceleration, which had a range of $\pm 2\,g$ (MVP-A3s-02b; Microstone Inc., Nagano, Japan), we analysed walking acceleration in the participants and horses. The three-dimensional acceleration sensor was placed on the upper part of the pelvis (i.e. waist backside) of the participants, and the participants walked for 3 min. In the horses, the sensor was placed in front of the saddle (pommel) in order to measure the acceleration that produces direct motor stimulation to the rider's body. The measurements were initiated after calibration of the sensor; each horse with a rider had a normal walk of 3 min. A sampling rate of 50 ms was used for recording the acceleration data. We obtained 3600 data for 3 min in each horse and in each participant and extracted 1024 continuous data (i.e. 51.2 s).

We separately obtained 1024 continuous acceleration data in the walking cycles, generated by a series of foot movements. The stride-phase data series were then normalised (0–100%) and the means and the standard deviations were calculated at 10% phases in the X, Y, and Z axes for all the participants and horses individually. The acceleration powers were determined, and human walking and horse walking were characterised by analysing the resulting stride acceleration curves (Fig. 1) (Byström et al., 2010). The mean acceleration values of each phase were compared among horses and participants by one-way repeated-measures analysis of variance (ANOVA) followed by Tukey's post hoc test.

For the analysis of walking quality, the frequency of the acceleration wave was calculated by Fast Fourier transform (FFT), and the main harmonic wave was identified from the power spectral density of FFT (Matsuura et al., 2008). The power spectrums were obtained at 0–10 Hz and divided into sections of 0.5 Hz frequency range, and then, the means and standard deviations were calculated. To determine the similarities between horses and humans, the presented peaks were analysed by the second derivative method using the graphing software OriginPro 8.5 (OriginLab Corporation, Northampton, MA, USA). The spectrum powers of each frequency band were compared between humans and horses by the Mann–Whitney U test.

We analysed the exercise intensity by examining the heart rate, breathing rate, and blood pressure of 127 healthy individuals (37 men and 90 women; age, 19–22 years) before (control) and after walking and horse riding (at a walking gait). We compared the data in the three conditions (control, horse riding, and walking) by one-way repeated-measures ANOVA followed by Tukey's post hoc test. Normality and homogeneity of variance were checked for all analyses. The level of statistical significance was set at $P < 0.05$.

Table 1
Profiles of the horses used in this study.

	Breed	Sex	Age (y)	Withers height (cm)	Stride length (cm)	Walking speed (m/s)
TH 1	Thoroughbred	Gelding	10	170	94	1.69
TH 2	Thoroughbred	Gelding	14	173	86	1.68
TH 3	Thoroughbred	Gelding	24	154	86	1.56
HK	Hokkaido	Gelding	12	138	73	1.38
Kiso	Kiso	Gelding	17	141	70	1.30
SF	Selle Francais	Mare	16	157	73	1.72
CRI 1	Criollo	Gelding	14	140	70	1.66
CRI 2	Criollo	Gelding	13	146	73	1.26
HB 1	Half-breed	Mare	11	119	58	1.38
HB 2	Half- breed	Mare	13	135	68	1.40
HB 3	Half- breed	Mare	16	155	81	1.35

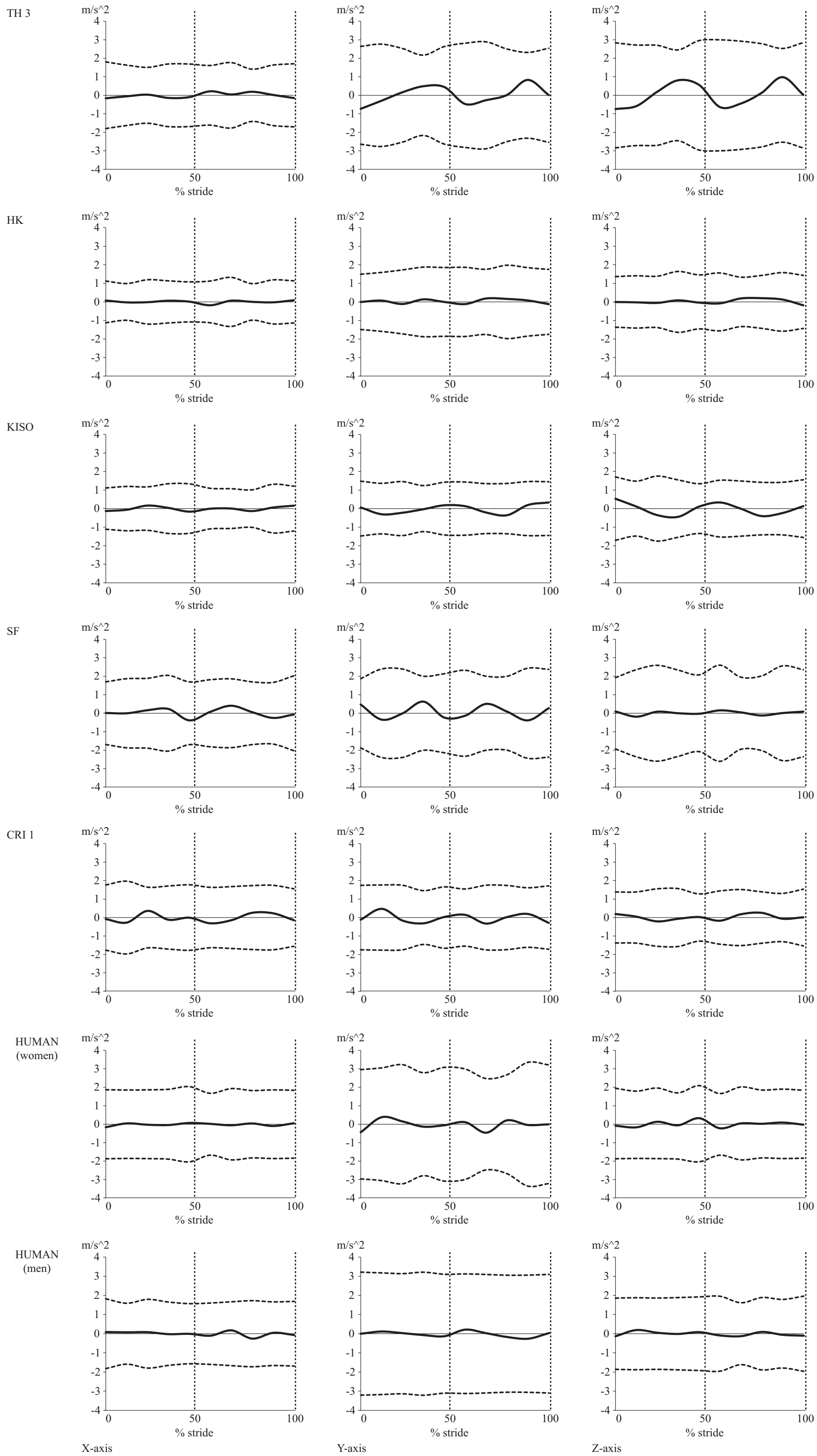

Fig. 1. Acceleration curves of horse walking (TH 3, HK, KISO, SF, and CRI 1) and human walking (men and women). The acceleration curves of human walking were obtained from representative individuals (men and women) selected among the participants. The solid lines indicate the mean curves, and the dotted lines indicate the standard deviations of means. The percent strides represent half step (one foot or the other) as 50% and one stride as 100%. The acceleration curves of some horse breeds overlapped those of humans, indicating a similarity in acceleration.

3. Results

3.1. Acceleration analysis

Fig. 1 shows the representative stride-phase acceleration data series for the participants (men and women) and TH 3, HK, KISO, SF, and CRI 1 horses. Marked differences were observed among the participants as well as among the horses. The results of ANOVA followed by Tukey's post hoc test showed significant differences between men and women in the X axis at 30–40% (men: $0.28 \pm 1.22\,\mathrm{m/s^2}$, women: $-0.49 \pm 1.27\,\mathrm{m/s^2}$, $P < 0.05$) and 80–90% (men: $-0.29 \pm 1.17\,\mathrm{m/s^2}$, women: $0.5 \pm 1.14\,\mathrm{m/s^2}$, $P < 0.05$) of stride phase. The accelerations of TH3 were significantly higher than those of men in 80–90% of phase in Y axis (TH3: $0.83 \pm 2.32\,\mathrm{m/s^2}$, men: $-0.26 \pm 3.06\,\mathrm{m/s^2}$, $P < 0.05$) and Z axis (TH3: $0.98 \pm 2.53\,\mathrm{m/s^2}$, men: $-0.05 \pm 1.8\,\mathrm{m/s^2}$, $P < 0.05$). The significant differences were not shown between other horses and human strides. When compared between TH3 and KISO, in some (0–10, 30–40, 50–60 and 80–90%) of stride phases, statistically differences of acceleration values were alternate in Z axis. The 80–100% phase accelerations of TH3 were also higher than that of SF in Y axis significantly (TH3: $0.83 \pm 2.32\,\mathrm{m/s^2}$, SF: $-0.39 \pm 2.44\,\mathrm{m/s^2}$, $P < 0.01$). The stride-phase acceleration curves of the horses corresponded with those of the participants, although differences were found in the thoroughbred horse. Differences were also observed in the acceleration stride curves among the horses, with the acceleration curves of TH 3 being higher than those of the other horse breeds.

3.2. Spectral analysis

We identified the main harmonic wave from the power spectral density of the FFT in each human and horse acceleration. The acceleration spectra of participants and horses are shown in Fig. 2. In human walking, the frequency peaks were as follows: X, 2.5–6.5 Hz of four peaks (men: 2.5–3.0, 4.5–5.0, and 6.0–6.5 Hz; women: 2.5–3.0, 4.0–4.5, and 6.0–6.5 Hz); Y, 2.5–9.0 Hz of six peaks (men: 1.5–2.0, 3.5–4.0, 5.5–6.0, and 7–7.5 Hz; women: 1.5–2.0, 3.5–4.0, 5.0–5.5, 7–7.5, and 8.5–9 Hz); and Z, 1.5–6.0 Hz of four peaks (men: 1.5–2.0, 3.5–4.0, and 5.5–6.0 Hz; women: 1.5–2.0, 3.5–4.0, and 5.0–5.5 Hz). In horse walking, spectral peaks were observed at 2.5–3.0 Hz on the X-axis; two peaks, on the Y-axis (1.5–2.0 and 3.5–4.0 Hz); and two peaks, on the Z-axis, with the first peak at 1.5–2.0 Hz and the second peak at 3.5–4.0 Hz. In the corresponding peaks (X, 2.5–3.0 Hz; Y, 1.5–2.0 Hz; Z, 1.5–2 and 3.5–4.0 Hz) between humans and horses, the spectra powers of horses were significantly higher than those of humans (men and women) in the X- and Z-axes ($P < 0.01$, Mann–Whitney U test) and were significantly lower than those of humans (men and women) in the Y-axis ($P < 0.01$, Mann–Whitney U test).

3.3. Analysis of exercise intensity

We compared the heart rate, blood pressure, and breathing rate of the healthy individuals in the control, walking, and horse riding conditions. There were no significant differences in the heart rate or breathing rate. The diastolic blood pressures in horse riding were slightly higher than those in walking condition, but the values in both conditions were lower than those in normal condition (control, 69.1 ± 12.5 mm Hg; walking, 63.5 ± 10.7 mm Hg; horse riding, 66.2 ± 12.2 mm Hg; $P < 0.01$, one-way repeated-measures ANOVA).

4. Discussion

In this study, we characterised the movement of the horse while walking and human ambulation, analysing the three-dimensional accelerations and evaluating the similarity in the movement patterns of human walking and horse walking. The gait movements showed continuous three-dimensional gravitational variations in acceleration ($\mathrm{m/s^2}$) and frequency (Hz), quantitatively and qualitatively.

The frequency peaks of horse walking corresponded with those of human walking (Fig. 2). Although the accelerations of human walking were not completely consistent with those of horse walking in all axes (Fig. 1), human walking and horse walking were similar accelerations because the comparison of accelerations in each stance phase between horse and human strides. Though the acceleration of TH3 in Y and Z axis was slightly 10% different from men, correspondences were shown at the other of 90 percentages of stance. This corresponds to 90% motion in acceleration, and shows a similarity in walking. The only slight differences in acceleration and frequency powers were observed among the horse breeds as well as among the participants. The HK breed had an amble gait, whereas the other horse breeds had a diagonal gait. An amble gait has smaller movements than a diagonal gait. In this study, we found that the walking acceleration of the HK horse was lower than that of human walking, especially in the X- and Y-axes. The TH horses had higher stride acceleration in the Z-axis in comparison with humans and other horse breeds, as well as higher withers height, stride length, and walking speed. Unlike the other horse breeds, the TH breed had high forward and lateral accelerations, which could give the rider a sense of speed.

Walking is the most accessible exercise to enhance health and cardiorespiratory fitness. Various conventional walking programs, including swimming pool walking and/or dog walking, have been shown to improve health and fitness and reduce cardiovascular risks (Franklin, 2006). The sensory input provided by walking could stimulate brain activity, including that of the prefrontal cortex, which regulates movement control, attention, selective information processing, and the organization of goal-directed movements (Harada et al., 2009). In older people, walking could provide sensory inputs to improve cognitive functioning and dementia (Verghese et al., 2007). Ploughman et al. (2007) suggested that exercise helped to regulate the protein levels of brain-derived neurotrophic factor and that physical activities such as running or walking improved learning.

The exercise intensity of horse riding at a walking gait was similar to that of human walking, as indicated by the non-significant differences in heart rate and breathing rate between the two conditions. Horse riding and human

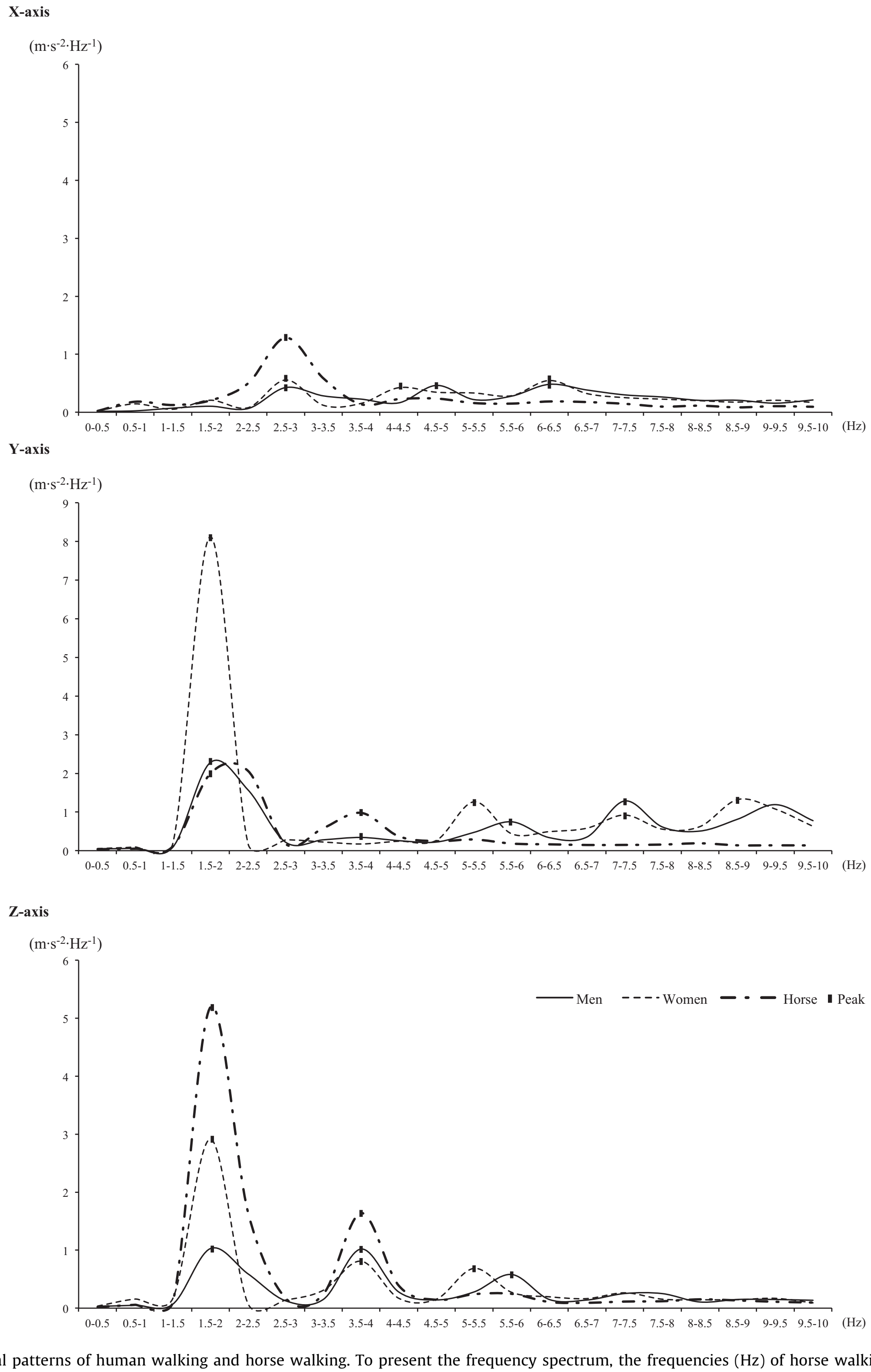

Fig. 2. Spectral patterns of human walking and horse walking. To present the frequency spectrum, the frequencies (Hz) of horse walking and human walking were analysed by FFT. The spectra of human walking were obtained from the 50 participants (21 men and 29 women). Each peak is indicated by a vertical dash. In horse gait, some major spectral peaks were observed. The frequency peaks of human walking corresponded with those of horse walking at 2.5–3.0 Hz on the *X*-axis, at 1.5–2.0 on the *Y*-axis, and at 1.5–2.0 and 3.5–4.0 Hz on the *Z*-axis.

walking decreased the levels of diastolic blood pressure compared with that in normal conditions. The advantages of a conventional walking program include a low drop-out rate and low exercise intensity (Franklin, 2006). However, a continuous walking activity is difficult for persons with physical disability. Our results indicate that horse riding at a walking gait provides the stimulation of a walking exercise more easily and effectively than does human walking. Thus, horse riding is even more efficient in providing motor and sensory inputs in the treatment of individuals with physical disabilities, as well as in achieving cardiorespiratory fitness and weight control.

Anderson et al. (1999) indicated that it was very difficult to objectively determine the suitability of the horse to be used in therapeutic riding programs with regard to the animal's temperament and reactivity, probably because other important traits (e.g. smoothness of gait) should also be considered. Hippotherapy or therapeutic horseback riding needs to be further developed as a treatment strategy to provide optimum benefits to patients with varying disabilities. The results of the acceleration analysis in this study demonstrate that horse walking is similar to human walking, and therefore, horse riding could offer many health benefits, especially for persons with ambulatory difficulties.

5. Conclusions

The present study shows that horse riding provides motor and sensory inputs through variations in gravity, and that the acceleration of the horse while walking was comparable with that of human walking quantitatively and qualitatively. Our results indicate that horse riding at a walking gait provides stimulation (i.e. acceleration) highly similar to that generated by human walking, and thus provides optimum treatment benefits to individuals with ambulatory difficulties.

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