Co-creative Walking Support as Music Therapy

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Abstract

Mutual adaptation process in musical communication is often used for walking support and rehabilitation. But this kind of supporting system is not realized yet. So the purpose of this research is to construct walking support system as a musical communication process. Our strategy is to extend Walk-Mate system, which realizes mutual adaptation process between human and virtual walker by exchanging step sound. We replaced this step sound to the music performance and showed the effectiveness in the experiment of walking support. The smoothness of gate cycle was improved in the both music performance condition and step sound condition. But in the music condition, the improvement of smoothness remained after the support walking. This result show the effectiveness of this proposed system as a walking support

1 Background

The walking support and rehabilitation of the elderly and the handicapper are often done by cooperative walking between therapists and patients. A music therapy is often used for the walking support[1]. The music therapy is one of the rehabilitations which is done by the rhythm cooperation between the music sound played by therapists and the body action of patients. The effectiveness of music therapy in the rehabilitation is remarkable.

On the other hand, the present walking supports are generally done by biofeedback[2]. Some of them controls music performance and resemble to the music therapy. But the purpose of these biofeedback methods is to control the patients themselves to the ideal condition which given by machine. This purpose is different from the purpose of rehabilitation which support to create a new body function walking. Thus, the improvement of walking motion does not stay after training in some patients who used the biofeedback method.

Thus in this research, we develop a new walking support system which realizes music therapy. In the music therapy, the rehabilitation is done by the communication between patients and therapist. To realize this process in walking support system, we have to construct the system, which is possible to adapt to human mutually. The cooperative

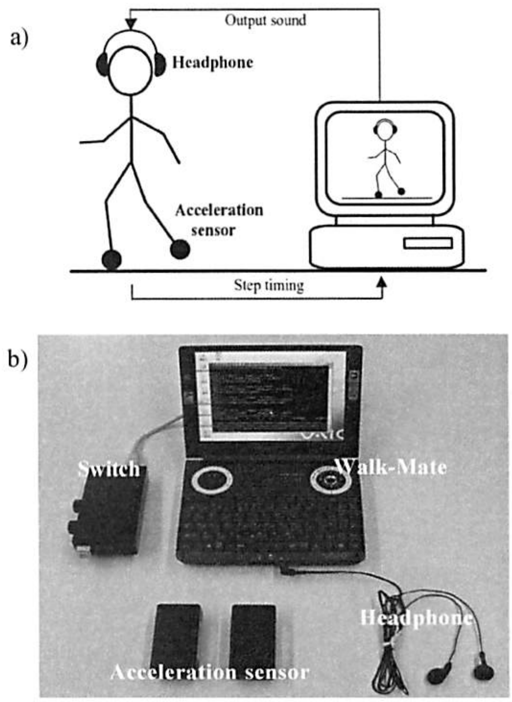

Figure 1: Walk-Mate system

walking support system "Walk-Mate" is one of the systems, which supports and develops human walking through the cooperation of walking step between human and machine[3]. Then, we construct walking support system based on music therapy by extend the function of Walk-Mate system to the music performing.

2 Experiment system

The experiment system is constructed basically by cooperative walking support system Walk-Mate we've reported before. Walk-Mate is the system, which achieve cooperative walking by exchanging the step timing of human and machine to synchronize their walking rhythms. As shown in Fig.1, this system shows the step sound of virtual robot moves in Walk-Mate by the headphone and measures the human step timing by using acceleration sensor attached on human ankle. By calculating the phase difference of each rhythm, this system can accelerate and control the walking speed.

In this research, we implement the additional function of music performance in the Walk-Mate. By using this function, it is possible to entrainment with human not only by step sound but also by music and step rhythm mutually. Then, it is possible to realize the walking support by cooperative walk and by using music performance.

The cooperative adaptation realized by the interface of the Walk-Mate system is constructed by a body model and an internal model. The body model synchronizes with human step rhythm through the entrainment and self construct the phase relationship between human and machine. The internal model controls and converge the phase relationship to the target value.

The body model is constructed by the mutual entrainment model as the equation is shown below[4].

$$\dot{\theta}_m = \omega_m + K_m \cdot \sin(\theta_h - \theta_m) \quad (1)$$
$$\dot{\theta}_h = \omega_h + K_h \cdot \sin(\theta_m - \theta_h) \quad (2)$$

In this equation ω_m and ω_h are the characteristic frequencies of the rhythm of Walk-Mate and human. θ_m and θ_h are the phase of the rhythm of Walk-Mate and human. And K_m and K_h are the coupling constants of each oscillator to the other. Through this interaction, this model itself constructs a phase relationship between human and machine. But in the Walk-Mate system, the only eq.(1) is implemented and eq.(2) corresponds to the human dynamics.

The internal model controls the phase difference $\theta_{HM}=\theta_h-\theta_m$ to the target value θ_{HMd} by the equation shown below.

$$\dot{\omega}_m = -\varepsilon \cdot \sin(\theta_{HMd} - \theta_{HM}) \quad (3)$$

This equation controls the phase difference by changing the characteristic frequency of body model. By the operation of these two models, cooperative adaptation is realized.

3 Experiment method

To evaluate the effectiveness of our system, we compare the ordinary systems. The one is the Walk-Mate, which only presents step sound. The other is the gait training, which presents static rhythm, and represents as biofeedback therapy. The evaluation is done by the smoothness and naturalness of walking motion. The music presented to human is "I've been working on railroad" whose accompaniment is constructed only by 4th note. The performance of step sound is constructed only by two kinds of pitch and this condition is the same as ordinary Walk-Mate system.

The one session of the experiment is done for 240sec, and the subjects walk alone freely at first 60sec (stage1), walk with the sound from Walk-Mate or static rhythm (stage2) at next 120sec, and return to free walking for 60sec (stage3). In this experiment, two kinds of sound (step sound and music) were used in cooperative walking and static rhythm walking, so four kinds of conditions are done.

This research is the pretest of the rehabilitation of handicapper. Thus in this experiment, we use five healthy 20th universe students who are given the handicap by using attachments to their knee. The attachments (Softec Genu, BSURTFEIND) are used to fix the right knee of each subject to virtualized hemiplegics patient. The degree to bend the knee is 0deg, so this condition virtualizes the walking motion which swing the hazarded leg to the side characterized by hemiplegics patient.

The evaluation is done by the smoothness and naturalness of walking motion. The smoothness of walking motion is evaluated by the fluctuation of gait cycle. The gait cycle is calculated by the interval of step timing of one side of the legs. So in this experiment, we measure the interval of left leg which is the opposite side of hazard leg. The fluctuation of gait cycle is defined as an absolute difference between the series of two intervals. This value shows the smoothness of walking motion and as the smoothness increases, the value decreases.

The naturalness of walking motion is evaluated by the time structure of gait cycle, whose evaluation is the same as the experiments done by Hausdroff[5]. This evaluation is based on the differences of a power spectrum of the gait cycle fluctuation. The power-low of gait cycle of healthy walker has 1/f fluctuation. Aginst this, the power-lows of the handicappers are the white noise. In this research, we evaluate the naturalness of walking motion by the gradient value of an approximation line of the power spectrum in the log-log scale.

The one session is done for 300 steps, but the first 20 steps of the session are omited from analysis subject to prevent from the adaptation time. Remaining 280 steps are used for the DFT analysis and the gradient n of the approximation line of the spectrum pattern on the log-log scale is calculated. This value n is the indicator of the naturalness of walking motion.

4 Results

Fig.2-Fig.5 are the typical results of temporal development of gait cycle in each condition. **Fig.6-Fig.9** are its average. **Table 1-Table 4** are the results of each subjects. We compared the fluctuation average of each stage to evaluate the smoothness of walking motion.**Fig.6**, **Table 1** are the results of music performance type Walk-Mate. The result shows the decrease of fluctuation average from stage1 to stage2 significantly and it indicates the improvement of the smoothness of walking motion. The smoothness of walking motion also remains at stage3 as stage2's cooperative walk. Against this, as shown in **Fig.7**, **Table 2**, the improvement of walking motion observed at stage2 does not remain at stage3 in the result of ordinary Walk-Mate system. This durability is the difference between new and ordinary system.

Fig.8, **Table 3** are the results of the walk with step sound by static rhythm and **Fig.9**, **Table 4** are the results of the walk with music performance by static tempo. In these cases, the improvement of smoothness of walking motion could not observed in any stages and subjects.

Fig.10 shows the typical analysis of power spectrum of

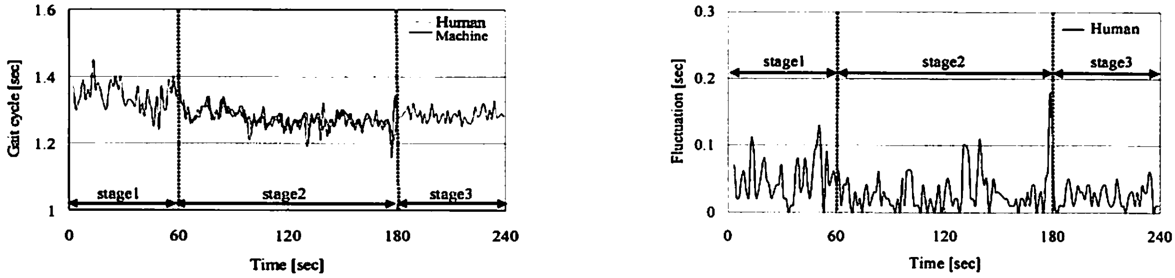

Figure 2: Temporal development of gait cycle with music (Walk-Mate)

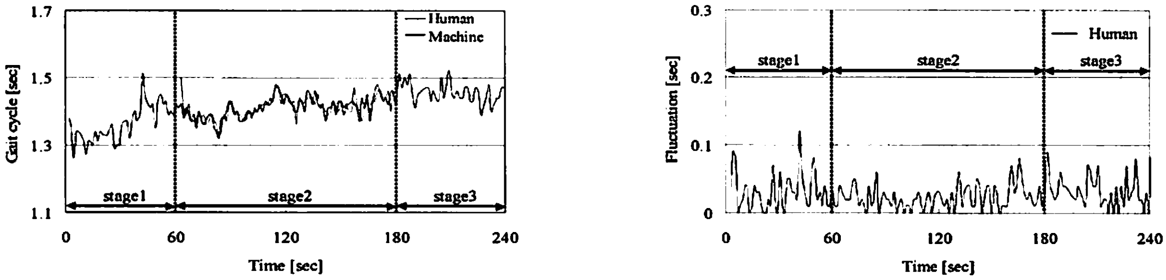

Figure 3: Temporal development of gait cycle with step-sound (Walk-Mate)

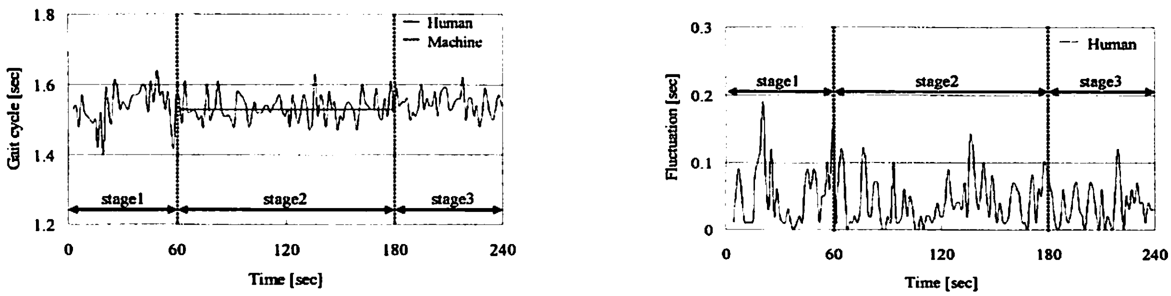

Figure 4: Temporal development of gait cycle with music (Forced entrainment)

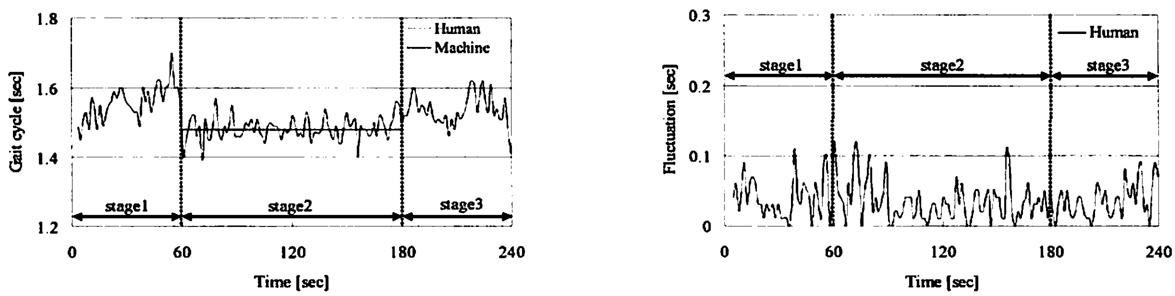

Figure.5: Temporal development of gait cycle with step sound (Forced entrainment)

gait cycle fluctuation. **Fig.11** shows the gradient average of power spectrum in each condition. From the left of the graph, its value is about healthfully free walk, a walking with music performance type Walk-Mate,a walking with ordinary Walk-Mate,a walking with static tempo music,a walking with static step rhythm, and a free walk with the hazard. It is observed that there is no significant difference between normal walk and music performance type Walk-Mate, and there is a significant difference between music performance type Walk-Mate and step sound type Walk-Mate (ANOVA). The gradient values of other conditions are significantly smaller than these values.

From these results, it is shown that the durability of the effectiveness of Walk-Mate is improved and the naturalness of walking motion is improved as free walk. And the limit of the ability of biofeedback method is also shown.

5 Discussions

The significant improvement of smoothness of walking motion is observed in the cooperative walk with Walk-Mate which does not depends on the difference between music

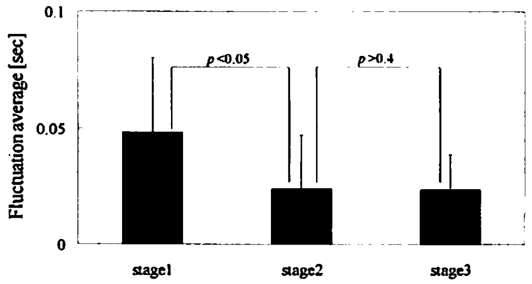

Figure 6: Fluctuation average of gait cycle with music (Walk-Mate)

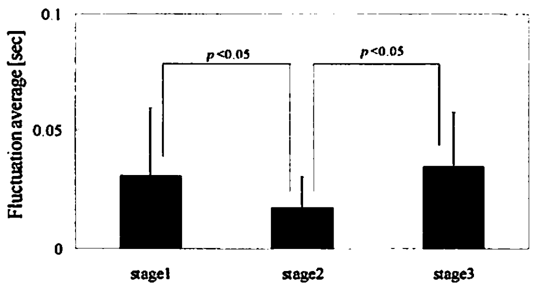

Figure 7: Fluctuation average of gait cycle with step sound (Walk-Mate)

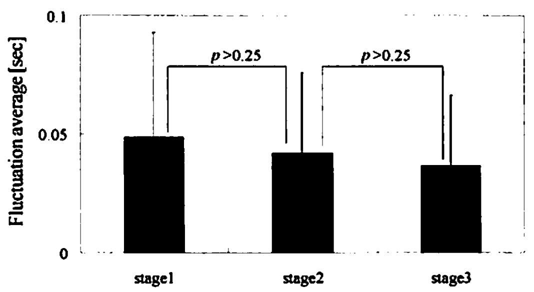

Figure 8: Fluctuation average of gait cycle with music (Forced entrainment)

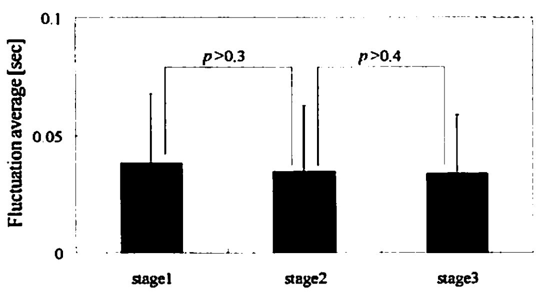

Figure 9: Fluctuation average of gait cycle with step sound (Forced entrainment)

Table 1 t-test of gait cycle fluctuation with music (Walk-Mate)

	state1	state2	state3
SubjectA	0.048	0.023	0.023
	**		0.48
SubjectB	0.077	0.058	0.069
	*		0.17
SubjectC	0.029	0.018	0.023
	**		0.12
SubjectD	0.060	0.032	0.032
	**		0.25
SubjectE	0.064	0.040	0.042
	**		0.41

** : $p<0.05$ * : $p<0.1$

Table 2 t-test of gait cycle fluctuation with step-sound (Walk-Mate)

	state1	state2	state3
SubjectA	0.031	0.017	0.035
	**		**
SubjectB	0.055	0.036	0.053
	**		*
SubjectC	0.028	0.018	0.036
	**		**
SubjectD	0.046	0.041	0.042
	0.28		0.45
SubjectE	0.040	0.029	0.042
	*		**

** : $p<0.05$ * : $p<0.1$

Table 3 t-test of gait cycle fluctuation with music (Forced entrainment)

	state1	state2	state3
SubjectA	0.048	0.042	0.037
	0.25		0.26
SubjectB	0.050	0.040	0.044
	0.13		0.28
SubjectC	0.042	0.035	0.031
	0.16		0.21
SubjectD	0.033	0.027	0.029
	0.15		0.37
SubjectE	0.032	0.030	0.054
	0.31		**

** : $p<0.05$ * : $p<0.1$

Table 4 t-test of gait cycle fluctuation with step sound (Forced entrainment)

	state1	state2	state3
SubjectA	0.038	0.035	0.034
	0.31		0.45
SubjectB	0.052	0.055	0.031
	0.42		**
SubjectC	0.041	0.044	0.043
	0.38		0.46
SubjectD	0.037	0.038	0.033
	0.48		0.25
SubjectE	0.038	0.034	0.024
	0.31		*

** : $p<0.05$ * : $p<0.1$

and step sounds. However, the stage after the cooperative walk, the smoothness of ordinary Walk-Mate system returns the condition before cooperative walk. Against this, the improvement of the smoothness of music performance type Walk-Mate remains even after the cooperative walk. The improvement of durability by using the music performance has the possibility of higher effectiveness of walking support and rehabilitation than that of step sound. At this point, the higher ability is expected in music performance type Walk-Mate.

Against this, there is no improvement of smoothness of walking motion in the condition of static tempo regardless of music and step sound. These results show the only music performance does not participate in the improvement simply. Especially, the biofeedback therapy is the typical method to control walking tempo to the static target. These results indicate that the gait trainings which using metronome or pitch control can't expect the improvement of walking motion.

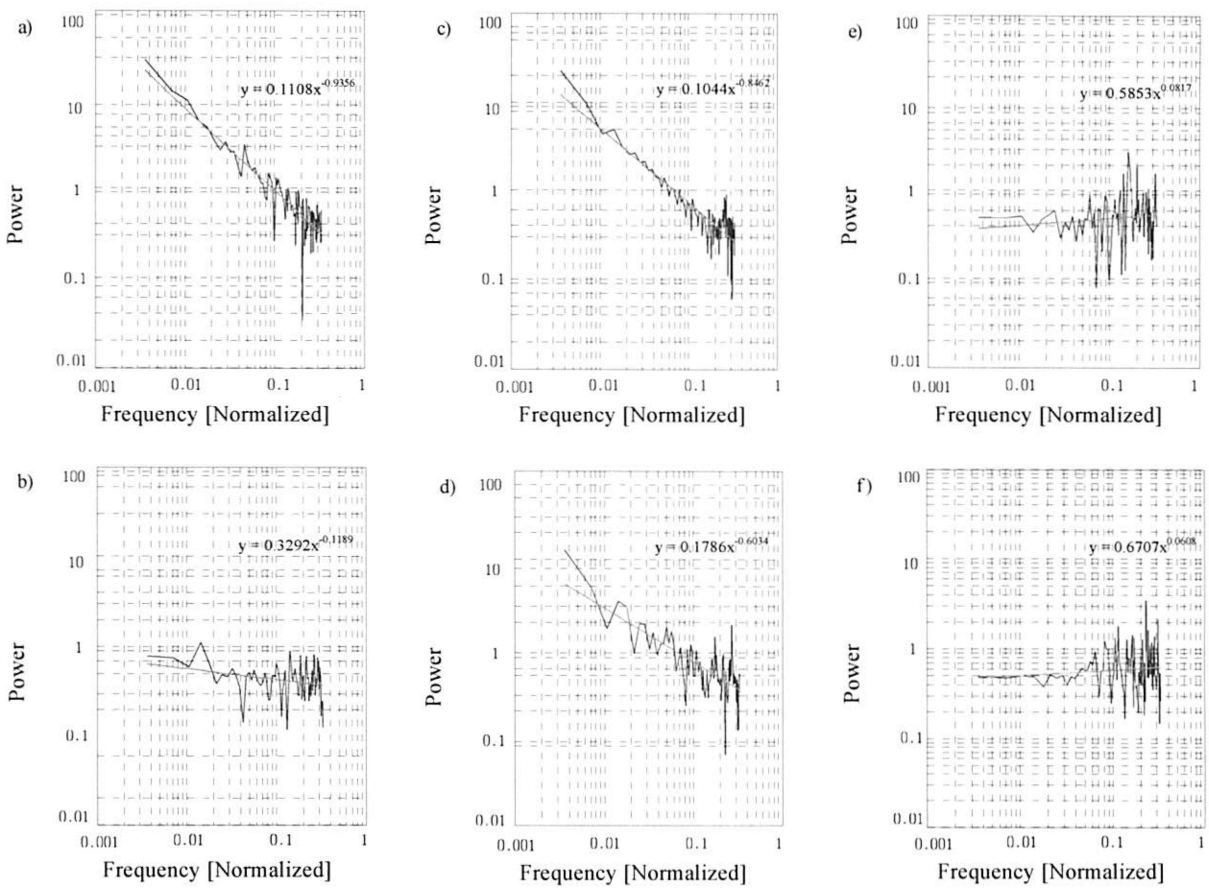

Figure 10: Power spectrum of gait cycle

a) Normal, b) Handicapped, c)Walk-Mate[Music], d) Walk-Mate[Step sound], e) Forced entrainment[Music], f) Forced entrainment[Step sound]

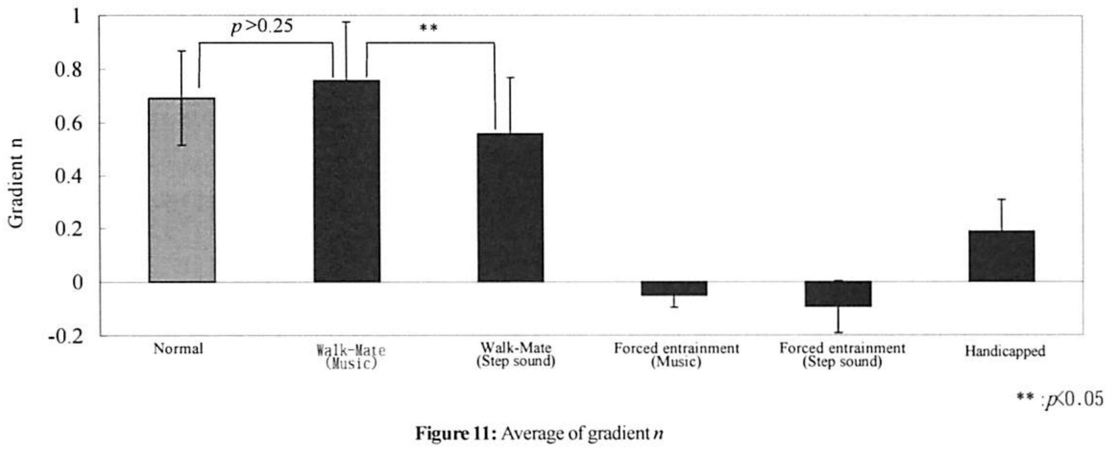

Figure 11: Average of gradient n

Thus, the improvement of walking function is realized by Co-creative walking support achieved by mutual adaptation between patient and therapist, and the music performance maintains the improvement.

In the results of the power spectrum, which show the naturalness of walking motion, the 1/f fluctuation characteristic is observed in the normal condition the same walk as the previous research of Hausdroff. And the gradients of power spectrum of the handicapped walk approach to the same noise as the result of real patient. This result means the subject condition used in this research is similar to the condition of real patient.

Against this, the gradient of power spectrum of fluctuation in the cooperative walking with Walk-Mate approached to the normal walk. Especially, in the music performance type Walk-Mate, there is no significant difference from the gradient of normal walk. This result shows the improvement of naturalness of walking motion by using Walk-Mate system, and it is increased by using the music performance. At this point, the higher ability is expected in music performance type Walk-Mate.

On the other hand, there is no significant difference of the gradient of power spectrum between silent and with static tempo in hazndicapped walking. These are regardless of difference between step sounds and music performance, and indicate that natural walking motion can't obtain by the biofeedback method. Thus, in the same way, the improvement of natural walk is realized by Co-creative walking support achieved by mutual adaptation between patient and therapist, and the music performance increases the improvement.

Therefore, the music performance type Walk-Mate system has the advantage of durability and naturalness in the rehabilitation. In future works, it is necessary to experiment the effectives to real patients.

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