Co-emergence Processes in Cooperation between Humans

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Abstruct

We analyzed the Co-emergence process on the cooperative walk between two humans. As result, we found a cyclic process based on the following two control processes. One process is the realization of footsteps' coherence between the cooperative walkers. The other is the control of the footsteps' coherence by the mutual relations with the fluctuations of the arms' swing, connected with the attention. Additionally we found that the arms' fluctuations take flexible synchronizations between the cooperative walkers. These results suggest that the synchronization of the cyclic process realize the Co-emergence of the cooperative walk flexibly.

1. Introduction

Humans are able to realize the suitable relation by mutual adaptation simultaneously, according to the situation. In this study, we propose the new man-machine system regarding such kind of "Co-emergence" process[1] as ideal. As example, we have focused on the humans' walk-support by cooperative walk between the therapist and the elderly handicapped, and have proceeded with the development of a walk-support technology which is based on the cooperative walk[1]. Here, we report about the results of the analysis of the Co-emergence process on the humans' cooperative walk based on this technology.

On these days, the machines have the ability to do walk-support, which only humans have been able to do, with the development of them. As examples, "Powered wheelchair", "Intelligent prosthesis"[2], "Power assisted walking support device"[3], "Powered suits"[4] exist. They are not support tools such as the walking stick or walking flame, but the machine that has the motive power and the control mechanism. Thus the machines provide the necessary functions, which the machines have already contained, to the users. In this case, there are the advantages to realize the constant support for the user's walking in spite of the handicaps and his ability to use it because the machines are able to reduce the load for the users. However the functions are close to the inside of them, so it is difficult to Co-emerge the suitable functions for the walk-support according to the situations.

To approach such a problem, we have proceeded the walk-support robot to Co-emerge suitable support for the elderly handicapped through the cooperative walk as the open embodied interaction[1],[5]. From now, as an example of it, we have developed the walk-support machine "Walk-Mate"[6] which realizes the cooperative walk between the users and the virtual robot by the footstep sounds. Additionally, to clarify the effectiveness of it, we have proceeded the analysis of the Co-emergence process in the cooperative walk between human and Walk-Mate[7] and the application for the real elderly handicapped'walk-support[8]. However we have never analyzed the Co-emergence process in the cooperative walk between humans as the ideal of such technology. Therefore we analyzed the real Co-emergence process of the cooperative walk between two humans by measuring the body motions of them.

2. Method

a. Plan

The purpose of this experiments is to clarify the mechanism of the Co-emergence process on the humans' cooperative walk with the walk-support. Therefore we took up the cooperative walk between two humans as the typical situation on the walk-support, and analyzed this mutual adaptation process. Especially as the elements of the dynamics, we focused on the motion of the arm and leg, of which the human's walking motions consist, and analyzed the dynamic characteristic on the Experiment #1. Then we analyzed mechanism by measuring the temporal development of the motions on the Experiments #2 and #3.

b. Cooperative walk system

To realize a suitable walk-support by the cooperative walk, it should be important to adapt both walker's tempo of walking mutually according to the situations. To measure the Co-emergence process as the mutual adaptation process of walking motion, we focused on the footsteps as an expression of the walking motion, and developed a system to realize the mutual adaptation of walking motion by a rhythm sound instead of footsteps between the subjects. Incidentally such kinds of walk-support by rhythm sound are applied to the real walk training for the dynamical syndrome represented by the gait disturbance on the patients of Parkinson syndrome[9].

This systems's setup is as shown in Figure1. The information about the footsteps were measured by touch sensors (OJIDEN,

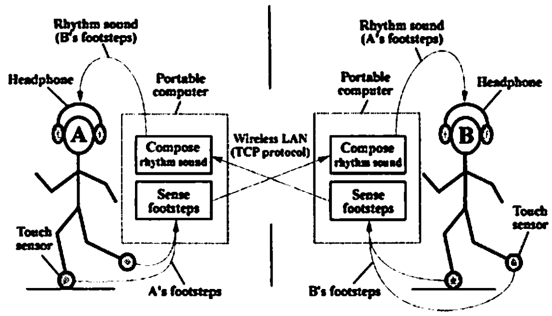

Figure1. Cooperative walk system.

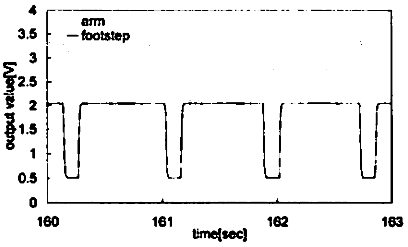

Figure2. An example of measured data.

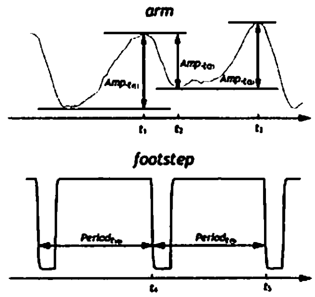

Figure3. Defininition of the measured data.

OT-NO-1) on the heels of the subjects' foot as the step-timings. The information was recorded by the portable computer (TOSHIBA, Libretto70), and transfered to the other subject's portable computer by using TCP protocol on Local Area Network. When the information reached to the other subject's portable computer, he hears the rhythm sound which correspond to the other subject's footsteps. The accuracy of time constant is less than 0.01sec.

c. Measurement system

The purpose of this system is to measure the dynamics of arm and leg simultaneously. The motion of leg is measured as the data of step timing of foot by the touch sensor mentioned on the last section, and the motion of arm is measured as the data of angular oscillation of elbow, which is measured by an angular sensor (NIHON KODEN, EG511H). This data is sent to telemeter (NIHON KODEN, WEB-5000) by its transmitter (NIHON KODEN, ZB-5812) and converted with 128Hz into discrete voltage data, which can be recorded by the PC (IBM, ThinkPad 570) through the A/D converter (ADTEK, AXP-AD02). An example of the measured data is shown in Figure 2. The feet's data was recorded as the time when the measured voltage drop down. The voltage value of the arm's data is proportional to the angular value. The value 0V correspond to the status that the elbow is straight, and the more the value increase, the bent the angle of elbow become. The amplitude of the arm's angular oscillation is defined as Figure3.

d. Experimental conditions

We take 6 subjects (native Japanese, twenties, male, students). At the experiment #1 and #2, 4 of them (A, B, C, D) formed groups of two (divided into other rooms), and walked along the circular tracks in the quiet enough rooms with the measurments of the touch timing of the feet and the angular oscillation of the arms. And at the experiment #3, the other subject E or F walk with subject A or B whose joint of the right knee was fixed on straighten by the knee orthosis (PACIFIC SUPPLY, 3560) as the condition of the experiment #2. These condition were measured under all possible, which are 6 patterns on the experiment #1 and #2 and 4 patterns on the experiment #3. We had already confirmed that all subjects were able to percept the rhythm sound, and required to concentrate only to hear it during the cooperative walk.

d1. Experiment #1

The motor center that relates the control of the walking motion is classified into the low level nervous system on the spinal cord and the brain stem, and the high level cerebral nervous system on the cerebrum[10]. Especially the latter relate the "attention"[11] for the cognition of the environments, so that suggest it takes very important role to realize mutual adaptation of the walking motion for the walk-support. Accordingly, in this experiment, we analyze the characteristic of the elements of the Co-emergence process by the control of the attention on the cooperative walk.

On this experiment, we set the two conditions (normal and attention condition) and compare them. In the normal condition, the subjects only walk 60sec with the cooperative walk system. On the other hand, in the attention condition, the subjects do the cooperative walk same as in the normal condition combined with a 5-words-memorization task, to attach the attention[12],[13]. This is generally called "Dual-Task method" to reduce the processing ability for primary task as the cooperative walk by make them do the secondly task as the memorization task. The detail of the memorization task was followings; The subjects were showed 5words which were composed 3~5 Mola *Hiragana* or *Katakana*(Japanese letter) 3sec by the computer display just before they start to cooperative walk. Just after that, they do cooperative walk with keeping the memory of these words. Just finish walking, the subjects was required to answer back those by the oral expression.

d2. Experiments #2 and #3

In these experiments, we measure the temporal development of the elements on the Co-emergence process by the cooperative walk in 600sec as same as the normal condition on the experiment #1, and analyze the relation of the interaction from the results.

3. Results

a. Experiment #1

We set the two kinds of the experimental conditions based on the attention. Incidentally from the results of the memory task, the average percentage of the correct answer was 90.83%. So it was confirmed that the subjects attained the task actually.

To analyze the dynamics of the legs, the auto-correlation coefficient of the all subjects' period of the footsteps from the *lag*0 to the *lag*10 was calculated as the way of Figure4. The average and the standard error are shown in Figure4. The time scale of the1 *lag* was almost 1sec because the average of walking period in cooperative walk is 1.07sec(Normal condition: Ave.= 1.06sec S.D.=0.03sec, Memory condition: Ave.=1.08sec S.D.=0.03sec). The object area to be analyzed was the starting time of the cooperative walk after 10sec to 60sec, which duration was 50sec. There are no significant colorations or differences between the normal condition and the memory condition. Thus the temporal developments of the footsteps are relatively random dynamics, which do not have the characteristic structures.

On the other hand, to analyze the dynamics of the arms, the auto-correlation coefficient of the all subjects' angular amplitude of the swing of arms was calculated on these conditions in the same way as the footsteps. The amplitude of arms' angular oscillation was defined in almost every half period of the walking motions. Therefore the dynamics is defied at almost half time-scale of the leg's dynamics. Thus the auto-correlation was calculated from the *lag*0 to the *lag*20 with the *lag*2 interval, as shown in Figure5. From the results, the normal condition took higher value of the auto-correlation coefficient than the memory condition, and that is the differences. In addition, the significant differences were observed in the area between the *lag*2 to the *lag*6 ($P < 0.05$). Thus the temporal developments of the arms' swing contain the dynamics based on the attention, which timescale is 1~3sec.

b. Experiment#2

From the results of experiment #1, it was clarified that the dynamics relate the attention. Accordingly we analyze the temporal development of the mutual interaction between the dynamics by measuring the footsteps' motions and the swing motions of the arms.

The relations between the footsteps of the subjects on the cooperative walk were analyzed as the temporal development of the coherence of the footsteps; that are the smallest time differences $\Delta_{t(n)}$ between the cooperative walkers on each footstep, as shown in eqn. 1.

$$Coherence_{t(n)} = \sum_{k=n-4}^{n} \left| \Delta t(k) - \Delta t(k-1) \right| , \qquad \text{(eqn. 1)}$$

On the other hand, the dynamics of the arms were measured by the amplitude of elbow's angular oscillations $Amp_{t(m)}$. However there are huge individual differences. Therefore to cancel the differences, we standardize the data by using the average value of the standard walking on each subject as $Amp_{t(m)}$. Then the data of arms' motions are analyzed as the fluctuations of the values, as shown in eqn. 2.

$$Fluctuation_{t(m)} = \left| \tilde{Amp}_{t(m)} - \frac{1}{10} \cdot \sum_{k=m-9}^{m} \tilde{Amp}_{t(k)} \right| , \qquad \text{(eqn. 2)}$$

From the measured data, we take up the 120sec durations for the analysis, which every value of the coherence took less than 0.5sec as the duration that seemed to be realized the mutual adaptation well.

As an example of the results, it was shown in Figure6 the temporal development of the subjects' fluctuation of the arms' amplitudes and of the footsteps' coherence when subject A walk with subject B. The tendency that there was some points which the arms' fluctuations increased more than 0.5 and the points were occurred cyclically with almost 10~30sec period was observed. In addition, such points were observed in both subjects, and additionally there was the synchronization between the temporal developments of the point. To clarify the tendency, the points where they correlated each other were put the halftone in the figure. Where such phenomenon occurred, the tendency that the coherence of walking period changes the little value to the large value was observed. To clarify this tendency, about the arms' data, the points that correspond the threshold value0.07 were shown by the dotted line, and the points were regarded as significant if it took more than the value. The dotted circles mark the coherence where the significant fluctuations were observed.

To evaluate the relation statistically, we compare the coherence of the footsteps between the average of all measured data, before 5sec and after 5sec the point where the arm fluctuate by these average value and standard deviation value of, as shown in Figure7. From the results, it was significantly observed at all 4 subjects the tendency that the coherence took significant smaller value ($P < 0.05$) than the average of all just before the arm's large fluctuation, then did the larger value ($P < 0.05$) than the before just after the arm's. The results suggest that there is the mutual relation between the arm's fluctuations of arm and the footsteps' coherence

To estimate the synchronization between the arm's fluctuations of the subjects quantitatively, the cross-correlation functions of these time series data about the arm's fluctuations of all groups of the subjects were calculated. In details, the areas for the analysis were divided in units of 5sec, and the bit array that took 1 if the arm's fluctuation was large or that took 0 in other case were made for the calculations of the cross-correlation function for all 6 groups.

Every 6 functions were shown in Figure8. At the 5 groups, the peak points of the functions are observed in the point 0sec. Thus it became clear that both time series almost synchronized each other. From the results, it was suggested that both subjects' fluctuations of the arms' swing synchronize each other through the mutual relations of the footsteps' coherence.

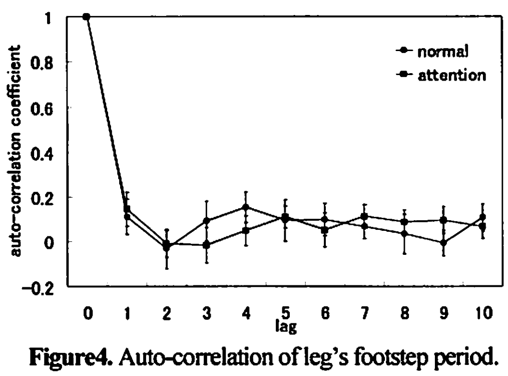

Figure4. Auto-correlation of leg's footstep period.

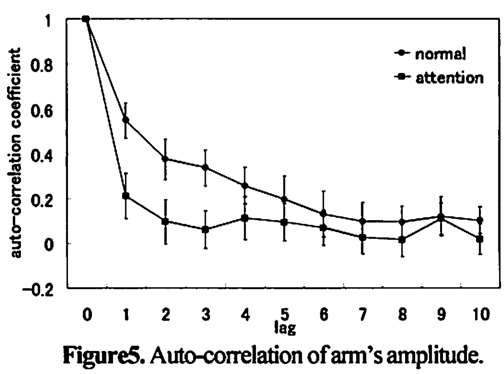

Figure5. Auto-correlation of arm's amplitude.

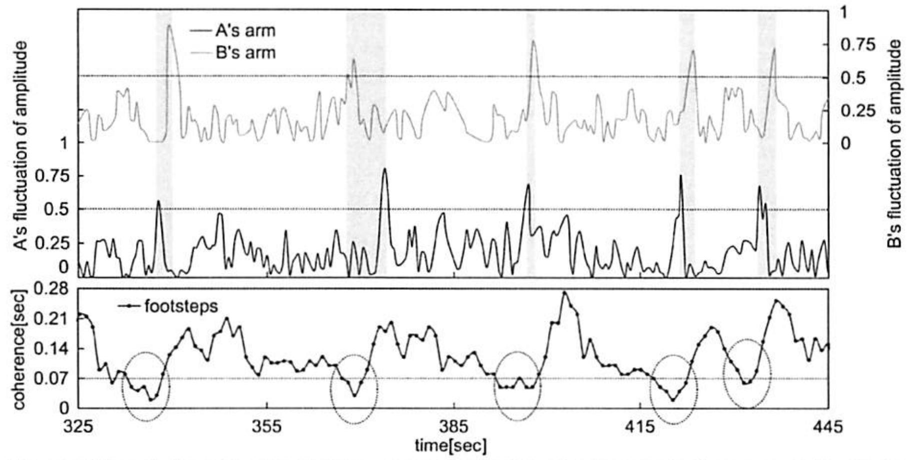

Figure6. Correlation of swing motions of arm and footsteps' coherence between normal subjects.

c. Experiment #3

Using dummy handicapped subjects whose joint of the right knee was fixed on straighten, this experiment was performed more closely to the real walk-support. As an example of the results, in Figure9, we show the temporal development of the subjects' fluctuation of arms' amplitude and of the footsteps' coherence when the dummy handicapped subject B walks with the normal subject D.

Mutual relations between the arms and the legs on both subjects as same as on the experiment #2. However the time scales of the B' cycles of the arms' fluctuation were longer than the time scales of the D's.

To estimate such tendency, we compare the frequency rate of the arms' fluctuations between the dummy handicapped subjects and the normal on this experiment with the rate between the normal subjects on the experiment #2 were observed. Figure10 shows the averages of the frequency rates on the experiment #2 and #3. Then we found that the rates on the experiments #2 and #3 took almost 1.2 and 0.5 respectively. This means the relations of the time scales of the arms' cycles on the experiment #3 were more asymmetric than on the experiment #2 with almost twice the rate. Thus it was suggested that the asymmetry of the subjects' characteristics make the cycles of the arms' fluctuations asymmetric on each group. Additionally to clarify the relations of the cycles on this experiments, the cross-correlation functions of these time series data about the arm's fluctuations of all groups of the subjects were calculated in the same way as in experiment #2, see Figure11. As the results, there are significant peaks on ± 10sec about all the

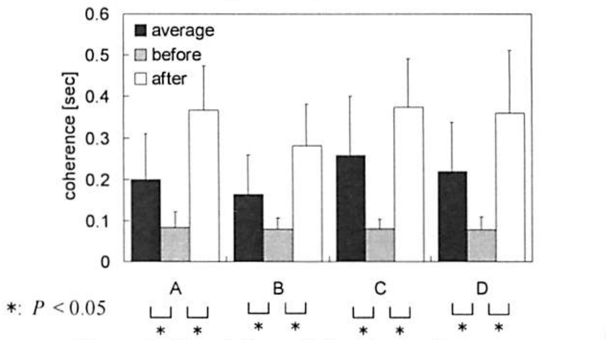

Figure7. Correlations of footsteps' coherence.

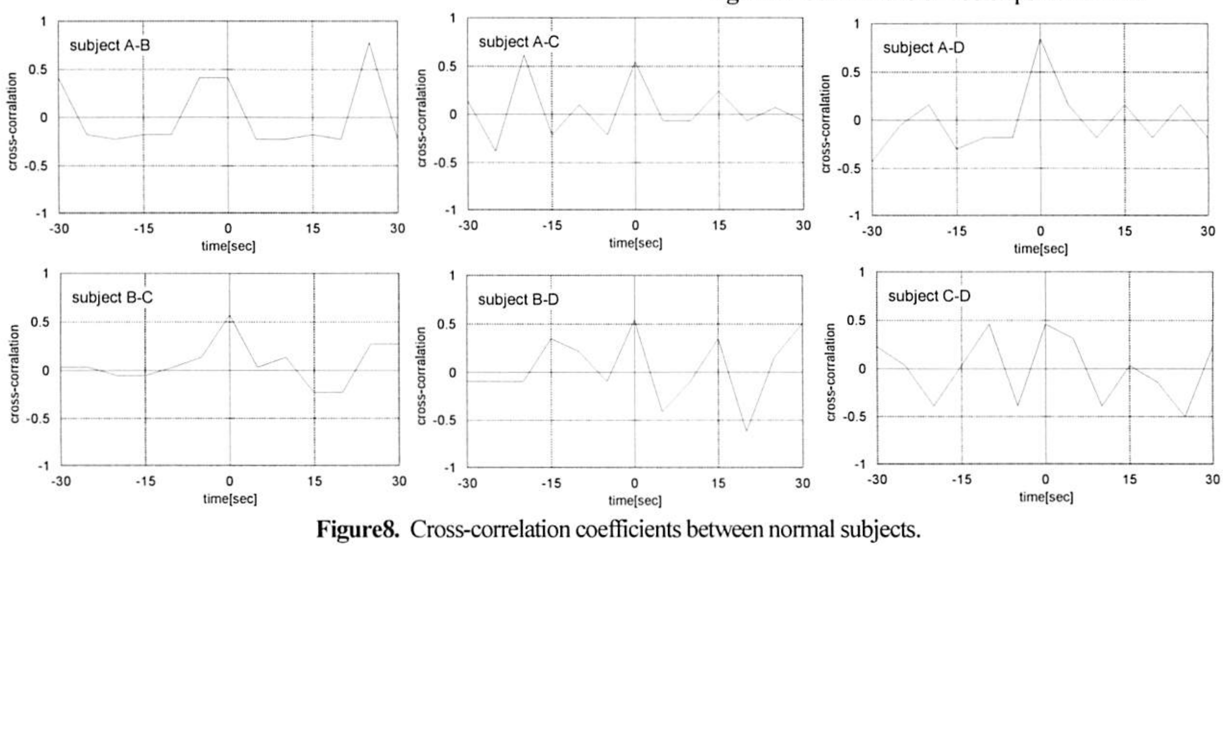

Figure8. Cross-correlation coefficients between normal subjects.

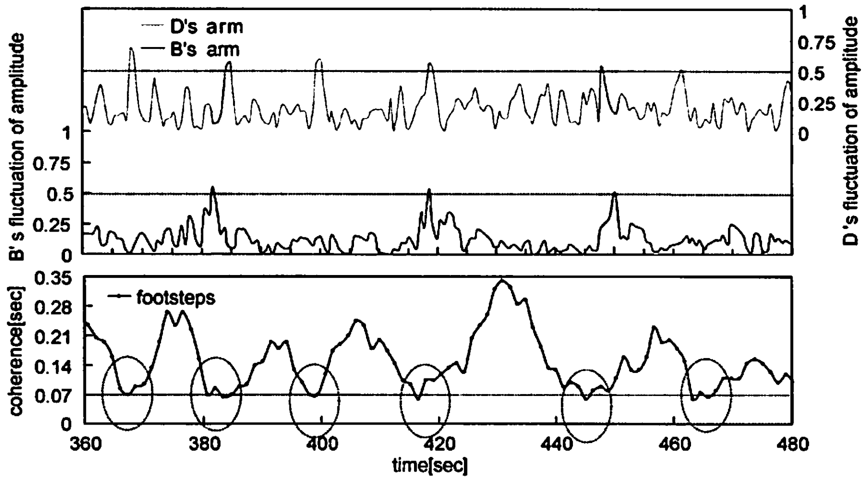

Figure9. Correlation of swing motions of arm and footsteps' coherence between normal subject and dummy handicapper subjects.

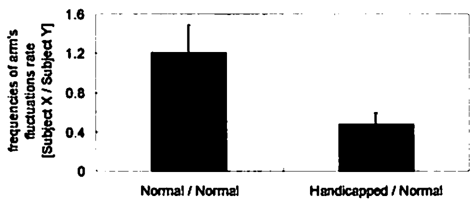

Figure10. Frequency of the arms' fluctuation rate.

groups. These results suggest that the normal subject synchronizes with the dummy handicapped more weakly than the normal with twice the rate.

4. Discussion

In this paper, to analyze the Co-emergence process, the experiments of the cooperative walk by the interactions of the footsteps were performed. Generally the cyclic and involuntary motion such as walking motions are mainly generated by the self-excited oscillation mechanism called CPG (Central Pattern Generator) [14] on the spinal nervous system.

Such mechanism relating the motions of the arms and the legs we measured. However from the results of the experiment #1, the dynamics of arms' swing motions contain the characteristic fluctuations influenced from the attention. The result suggest that the control of the swing motions of the arms relate not only the CPG but also the sensory processing system by the high level cerebral nervous system on the cerebrum such as the attention. On the other hand, it was clarified that the attention did not influence the footsteps' dynamics directly. Therefore those suggest that the arms and the legs have different dynamics and that the mutual relations between the arms and the legs are necessary for the analysis of the Co-emergence process.

On the experiments #2 and #3, analyzing the temporal developments of these motions, we found the dynamics to realize the coherence on the footsteps' interaction between the cooperative walkers. Additionally we may say that the dynamics was performed by the low level nervous system such as CPG because the dynamics of the footsteps do not relate the attention mechanism.

On the other hand, it was found that the characteristic fluctuations clarified on the experiment #1 occur on every 10~30secs and that there is a mutual relations with the footsteps' coherence. The result suggests that there should be the processes to control the coherence of the footsteps with the attention by the mutual relation with the arms' fluctuations.

Thus these results suggest the dynamics of the cooperative walk should have the two kind of control mechanisms about the footsteps' coherence between the humans, as shown in Figure12.

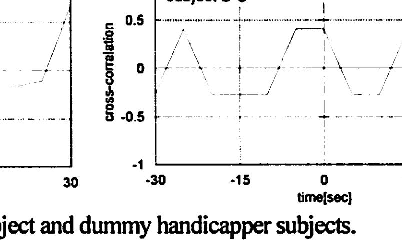

Figure11. Cross-correlation coefficients between normal subject and dummy handicapper subjects.

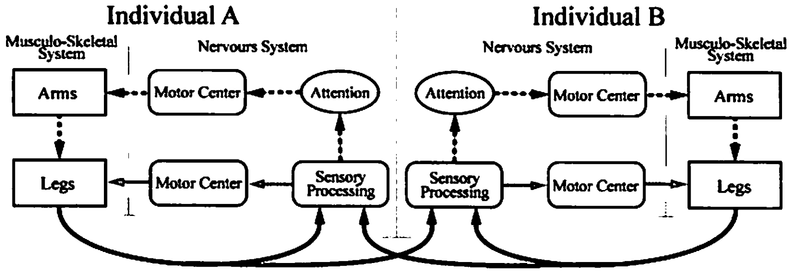

Figure12. Control process of the cooperative walk : at the case between the individual A and B.

Control Process #1: Coherence process of footsteps

Sense the footsteps' informations (black arrow) , and then control the Musculo-Skeletal system (gray arrow) through the low level motor system.

Control Process #2: Mutual process between arm and leg

According to the footsteps' coherence, sense the footsteps' informations (black arrow), and then change the coherence of the footsteps by the arm's fluctuations (dotted arrow) through the sensory process with the attention.

Also, the results suggest these two processes are connected each other through the footsteps' coherence. Thus it is suggested that these two processes are realized alternately as the cyclic processes with the cycles of the arms' fluctuations.

In addition, it was clarified that the cycles of the arms' fluctuations synchronize between the cooperative walkers, from the results of the Experiment #2. And, from the experiment #3, we found that the normal subject synchronized with the dummy handicapped more weakly than the normal with twice the rate.

These results suggest that such synchronizations processes are realized flexibly by the cyclic process based on the two control processes according to the combinations of cooperative walkers' characteristics. Thus we may say that the cyclic process realize the Co-emergence processes of the cooperative walk flexibly according to the situations.

5. Conclusion

In this paper, we performed the experimental analysis of the Co-emergence process on the cooperative walk between two humans. As the result, it was clarified that there is the cyclic process based on the mutuality of the two kinds control processes for the footsteps' coherence. It was suggested that the suitable cooperative process, according to the combinations of the subjects' characteristics, was Co-emerged by the cyclic process.

Our research group has ever focused on the emergence of the functions on the human's communications, and suggested that it was realized by the mechanisms called "Duality"[1]; expressed by the dynamics of consciousness and unconsciousness. On this experiments, the two kinds of control process on the different nervous level realize the cooperative walk. Therefore it was suggested that these Co-emergence mechanism relate the Duality.

In future works, to perform the analysis of the Co-emergence process of the real walk-support, we plan to extend the experimental condition.

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