Extending the World to Sense and Behave: A Supportive System Focusing on the Body Coordination for Neurocognitive Rehabilitation

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***Abstract*—We focus on the difficulty in people with cerebral palsy to perform motor skills in a coordinated and purposeful way and designed a robotic training support system for children with cerebral palsy, which enhance their motivation to do the training. The first target is to regenerate a balance between right and left motions in a rhythmic task. In the paddling task with both hands for rolling a long bar systematically, we found a pace-making dynamics with recovering an preferable motion to individuals and realize that it is the key to build extensive rhythm-based tools for improvements of cerebral palsy symptoms to capture the sense of the world and increase an active range of motion.**

Keywords-physical therapy (PT); robotic therapy; epigenetic robotics; neurocognitive rehabilitation.

I. INTRODUCTION

Cerebral palsy (CP) is the most frequent physical disability, or disorder, that mainly onsets in childhood. Over the past four decades, the number of patient has reported constant at 2 to 3 per 1,000 live births in industrialized countries, with low fetal mortality [1] [2]. Treatment of CP is a lifelong process that requires the collaboration of medical professionals including physiotherapists, the children, and their families. This is a sort of permanent disorder, but not unchanging in the viewpoint of neuro-developmental aspect.

The patients have problems in muscle tone, movement, and motor skills, especially in the ability to move body parts in a coordinated and purposeful way. Some patients also exhibit disability in other health issues, such as vision, hearing, and speech and learning problems, implying concerns about a relation to the impairment of intellectual development. Physical therapy treatments of medical professionals largely contribute to reconstruction in motor skills, and the procedure is well investigated and adequately equipped to care for patients with brain damage. In adult cases, patients are convinced by the experience of the physiotherapists and intend to do unpleasant trainings for recovery. However, children's expectations of the physical therapy even with well-equipped procedure often do not coincide with reality, and unwillingness often results.

Recently, brain plasticity enhanced by the presence of awareness, attention and concentration is focused in studies for recovery of the brain function [3] and clinical treatments of rehabilitation, so-called cognitive- or neuro-cognitive rehabilitation [4]. The combination of physical therapy procedures and retention of cognitive process in thinking and awareness starts anticipating for development of effective strategies that will open a new door in treatments of children's care, toward CP patients and its developmental difficulty [5].

In the present study, we are devoted to developing a robotic training support device (Fig. 1), which holds automated parts to enhance, support and burden a user's motion. The device is capable of recording their motions and performances as a training history to help visualize their developmental processes. As the framework, requirements for such devices are 1) modifiable structure, 2) adjustable kits and 3) rearrangement of parts in a structure, and 4) switching tasks and 5) changing challenging levels to the task difficulty as functions. In the viewpoint of the task design, we focus on a sense of cognitive space during the motor training. Ultimate goal is to provide a training method to encourage subjects to capture an appropriate cognitive space, and we start to investigate an effective method to regenerate a balance between right and left motions.

We hypothesized that a clue to the regeneration problem is to enhance an internal rhythm when subjects perform periodic movements, such as pedaling with legs and paddling with hands. Finally the concept of right-and-left coordination should be extended to an arbitral configuration, or a flexible sense of position in space, which are necessary for skills of musical instruments, like multiple percussions.

In the present paper, we describe an important relationship between cognitive and operational space in the viewpoint of neurocognitive rehabilitation in chapter II, our framework of a training support system for CP in chapter III, results of the pilot experiment to investigate an musculoskeletal pace-making dynamics during the paddling task in chapter IV, and the conclusion in chapter V.

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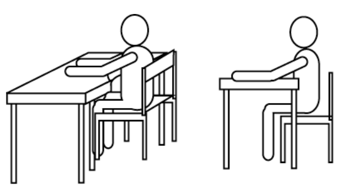
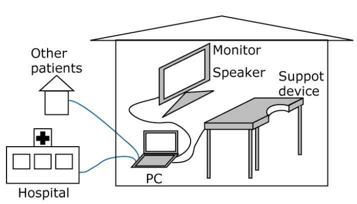
II. Cognitive and Operational Space

Cognitive motor control refers to processes that blend cognitive and motor functions in a seamless, interwoven fashion [6]. Through such experiences, the functions evolve in space and time at various levels of difficulty and complexity. Training programs in physical therapy mainly focus on improvements of motor abilities, which may distinct from the target of occupational therapy, but programs for children with CP are inescapable to include cognitive trainings, for example a task to require not only pointing a letter in text but also reading the letter and understanding what it describes (Fig. 2).

In a memory task, we observed a child with CP who can retrieve greater than seven random number presented by the therapist in a voice, suggesting an above-average IQ over children with the same age, but decreases its performance if random positions are presented in a table. Another child with CP who has taken an adequate physical therapy for movements in the paralysis side still demonstrates asymmetric operational areas between right and left hands (Fig. 4). One possible hypothesis is that cognitive and operational spaces link together and cognitive tasks to be aware of things in the paralysis side can be used as a complementary approach to the physiotherapy treatment for children with CP. We focus on the coordination between cognitive sense of space and behavioral structure in motion and designed a prototype of the robotic training support system to enhance the link between cognitive and operational spaces.



(a)

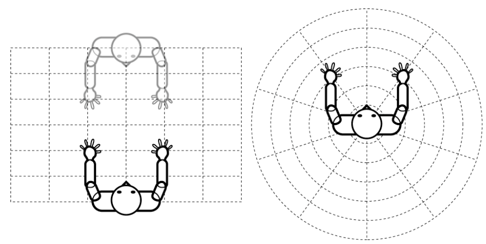


(b)

Figure 1. A prototype of the robotic training support device for execution of various handling tasks and monitoring the behavior. (a) Sensors spread over the flat table to detect hands' motion. Children with CP sit at the table because they mostly deficit self-standing ability in an early stage of rehabilitation and the device is devoted to examining how their cognitive developments proceed through memory tasks of visual stimulus and tracing hand movements in this case. (b) Portable PC is implemented in the device for task presentation, recording of behavioral data and communicating with physiotherapists in the hospital and other children with CP to play an interactive training game together.

III. Framework Design

We designed a training device for children with CP, which enhance their motivation to do the training through rhythmic game-like tapping devices. Palm-sized buttons can be used for designing such devices, by putting buttons with on the table and the buttons respond a touch by sound and light like musical instruments. Possible arrangements are given according to the subjects' deficits and we can consider various configurations (Fig. 3) to examine changes cognitive and operational areas between both hands (Fig. 2). However, our purpose does not design a musical instrument in a passive manner, but design an active device to be able to synchronize the internal rhythm that appears when individual subjects perform a rhythmic task at their own paces.



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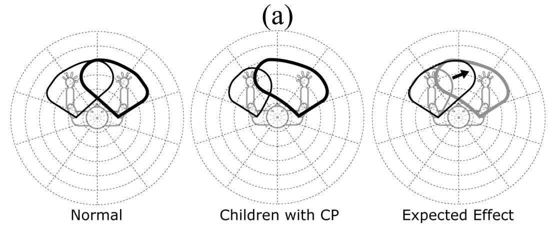

(b)

Figure 2. A concept of cognitive motor space. (a) (left) Allocentric coordinate or objective space to enable two persons to share the same space. (right) Egocentric coordinate or subjective space for handling by oneself. Cognitive development is considered to extend from egocentric to allocentric coordinates. (b) Cognitive and operational space in stages of rehabilitation. (left) In normal subjects, reachable spaces of right and left hands are consistent with spaces of easy-to-operate. (center) Patients with deficits in the right hemisphere of the brain are not good at handling things in the left side, known as hemispatial neglects [7]. (right) An ideal process of regenerate a balance between right and left motions after appropriate rehabilitations.

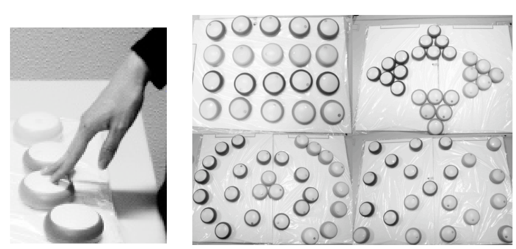

Figure 3. Palm-sized buttons are implemented in the table device. The button lightens the surface when touched and/or controlled by the PC according to the automated task program in an active manner (left), and are aligned in various ways such as grid-like, square, circle, and a spokewise structure (right). This helps to provide a tapping task in accordance with music.

IV. A PILOT EXPERIMENT

Firstly, we investigated a pace-making dynamics in motor trainings according to the concept of neurocognitive rehabilitation (Fig. 4a) and designed a padding task of hand motions [8] with two options: 1) with/without circular guides in both sides for navigating cyclic motions (position guidance) and 2) with/without balls in both sides for enhancing forces in cyclic motions (acceleration guidance). We built the equipment for the task and the real-time recording system of motion information through accelerometers (Fig. 5) by using the Nintendo Wii remote controller [9] [10] with the real-time Bluetooth wireless communication to an external PC (Fig. 6).

As the first step, six normal subjects were trained in the paddling task without guides and without balls, which consists of continuous five sessions (#1-#5) of a minute with interval breaks of five minutes. In the observation of paddling motions of a subject, we found a certain period of cyclic motions at a constant pace and a cracking between periods (Fig. 7). Interestingly, our experimental data exhibits a recovering dynamics to connect constant periods, with semi-conscious deorbit process (black lines in Fig. 7, 8) and conscious or quasi-conscious back-on-track process (blue lines in Fig. 7, 8) in Session #1. Due to the tendency to enlarge the constant period, the number of cracking decreases which is also observed in the frequency component analysis (Fig. 9). This tendency was observed in other subjects except in performances at the slow pace of cycling. This fact suggests that this phenomenon requires a certain workload for individual subjects, and this indicates the existence of a comfortable pace-making in the paddling task as the result of a synergy among the subject's internal rhythm, constraints of the support device and effect of training, such as habituation and learning.

V. CONCLUDING REMARKS

We introduced a concept of relationship between cognitive and operational space in the viewpoint of neurocognitive rehabilitation concepts, and demonstrate a pilot experiment to investigate an integral pace-making dynamics during a paddling task. We hypothesized that a clue to the regeneration problem is to enhance an internal rhythm when subjects perform periodic movements, such as paddling motions with hands. In further analysis and developments of the device and task design, we attempt to apply this result to the framework in an arbitral configuration, which enable the device to supply complex rhythmic and coordinating motions accompanied with memory skills in a cognitive space. For extending to the table-shaped device with palm-sized buttons aligned in a various structure, the device may require to detect the integral pace that is generated from such a synergy among the subject's internal rhythm, task constraints and learning effects and to synchronize it as a tempo of the music. It is expected to enhance the coordination between cognitive and behavioral sense, which may be observed as changes operational areas of both hands. This rhythm-based cognitive motor training coupled with the supportive autonomous system opens new doors for a self-sustained interactive rehabilitation.

ACKNOWLEDGMENT

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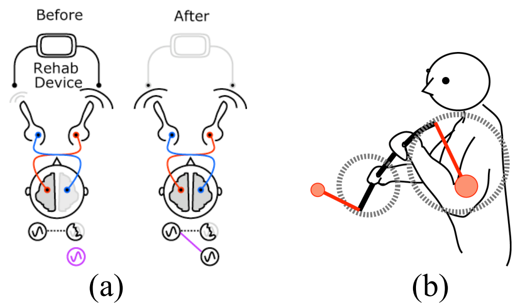

Figure 4. A possible rehabilitations process for reorganization through rhythmic motions. (a) An expected process of rehabilitations through the device, which is inspired from [11][12]. (b) Our proposed paddling taks with the 180cm bar, which allows a certain flexion according to the cyclic motion like a fishing pole. The task has two options: with/without circular guides in both sides for navigating cyclic motions (position guidance) and with/without balls in both sides for enhancing forces in cyclic motions (acceleration guidance).

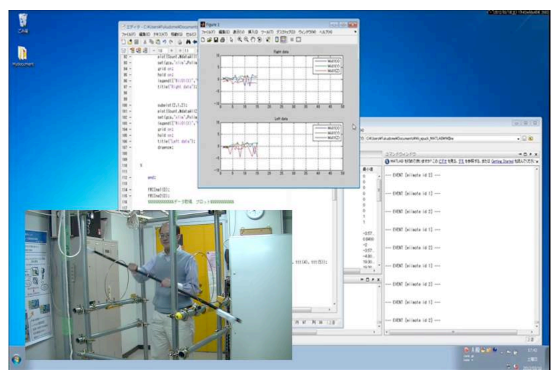

Figure 5. A demonstration of the paddling task. The left-bottom panel denotes a snapshot of the paddling motion in the equipment. The top plot exhibits a real-time observation of values from three dimensional acceleration meters (Fig. 6), which attached on both ends of the bar. The recording system was designed by MATLAB.

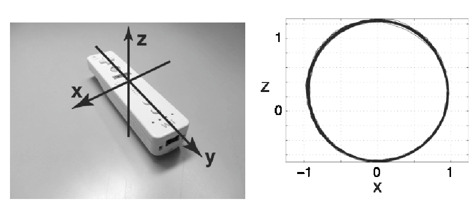

Figure 6. A Wii remote controller to connect to the PC via the wireless Bluetooth communication. This includes acceleration sensors with three orthogonal axes. (right) X-Z accelerometer values in machine rotations with a constant power.) (Figures from [10])

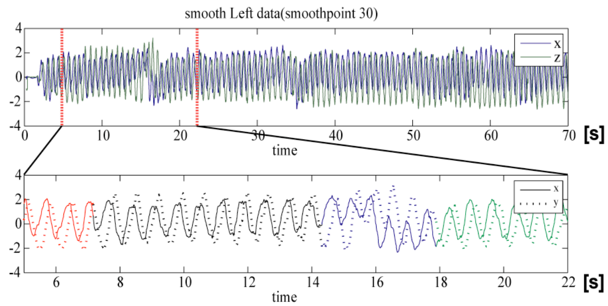

Figure 7. A temporal evolution of accelerometer values in the paddling task. (a) Experimental data of a subject in the first sesssin #1, for 70s. (b) A highlight of a recovering process connecting two constant periods, which consists of a stable period (red), deorbit period (black), back-on-track quick process (blue) and recovered stable period (green).

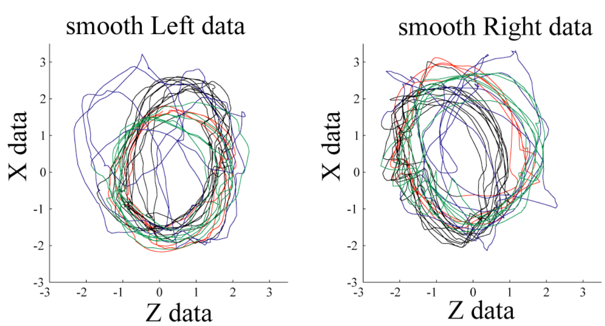

Figure 8. Replotting the recovering process of Fig. 7 in the X-Z accelerometer coordinates. This visulaizes an attractor dynamics to differ the stable orbit and the deorbit processes, and to make sense two stable periods (red and green) are consistent. Line colors are the same in Fig. 7.

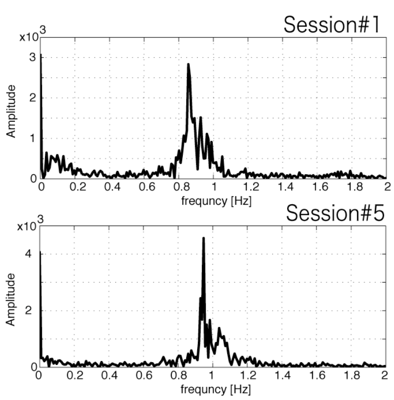

Figure 9. FFT analyses among different sessions #1 and #5, which is obtained from the same subject in Fig. 7 nad Fig. 8. Peak positions are similar in two sessions, while the frequency distribution is getting sharper with a single peak, suggesting the increasing of stableness of the paddling motions at a constant speed.

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