Neurocognitive rehabilitation approach for cerebral palsy syndrome by using the rhythm-based tapping tool to extend fields of perception and motion

M Fukudome¹, H Wagatsuma¹,², K Tachibana³, K Sakamoto⁴

¹Department of Brain Science and Engineering, Graduate School of Life Science and Systems Engineering, Kyushu Institute of Technology, 2-4 Hibikino, Wakamatsu-Ku, Kitakyushu, JAPAN
²RIKEN Brain Science Institute, 2-1 Hirosawa, Wako, Saitama, JAPAN
³Department of Physical Therapy, School of Health Sciences, Ibaraki Prefectural University of Health Sciences, 4669-2 Ami, Ami-Machi, Inashiki-Gun Ibaraki 300-0394 JAPAN
⁴Research Institute of Electrical Communication, Tohoku University 2-1-1 Katahira, Aoba-ku, Sendai 980-8577, JAPAN

fukudome-marie@edu.brain.kyutech.ac.jp, waga@brain.kyutech.ac.jp, tachibana@ipu.ac.jp, sakamoto@riec.tohoku.ac.jp

ABSTRACT

We focus on the difficulty of children with cerebral palsy to perform not only motor skills but also cognitive tasks, and hypothesize that rhythm-based tapping tasks help to enhance abilities of motions and cognitions cooperatively, if a personally-tailored rhythm is provided. In the experiment with the prototype tapping device, we found that a misalignment of the pacemaker with the internally-comfortable tempo brings subjects a feeling of discomfort and declination of performance if the task is in a rushed condition. This result suggests that a self-motivated rhythm may be enhanced through synchrony with the external rhythm, while it is disturbed by a gap between internal and external rhythms. This is an important step towards developing a rhythm-based rehabilitation method and a design principle focusing on subjects’ individual internal rhythms.

1. INTRODUCTION

Cerebral palsy (CP) is the most frequent physical disability, or disorder, that onsets mainly in childhood. Over the past four decades, the number of reported CP patients has remained constant at 2 to 3 per 1,000 live births in industrialized countries, with low fetal mortality [Molnar, 1991]. Treatment of CP is a lifelong process that requires the collaboration of medical professionals including physiotherapists, the affected children, and their families. This is a type of permanent disorder, but it is not unchanging in terms of the neuro-developmental aspect.

The CP 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 deficits in other areas, such as vision, hearing, and speech and learning, raising concerns about impairment of intellectual development. In other words, those deficits are caused by large-scale damage in the brain. Physical therapy treatments by 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 often remember previous experiences with physiotherapists and are prepared to do unpleasant activities for recovery. However, children’s expectations of the physical therapy, even with well-equipped facilities, often do not coincide with reality, and unwillingness often results.

Recently, brain plasticity enhanced by awareness, attention and concentration is a focus in studies of recovery of brain function and clinical treatments of rehabilitation—so-called cognitive- or neurocognitive rehabilitation. The combination of physical therapy procedures and retention of cognitive process in thinking and awareness aims for development of effective strategies that will open a new door in treatments for child CP patients and their developmental difficulty.

We have been devoted to developing a robotic training support device [Fukudome and Wagatsuma, 2011; Wagatsuma et al., 2012], particularly focusing on the self-motivated rhythm in motions (Fig. 1). The central
pattern generator (CPG) is well known as the common nervous mechanism embedded in the spinal cord of the animal body to control multiple limbs cooperatively and generate a wide variety of functional motor patterns, such as walking, stepping and running [Taga et al., 1991]. Synchronization between rhythmic movements of different limbs, which is caused by a collective neural activity in the brain, strongly governs the performance of both involuntary and voluntary movements (Fig. 1b) [Harken et al., 1985]. We hypothesized that necessary regeneration of the nervous system in the brain can be improved by the enhancement of an internal or self-motivated rhythm, which is easily reproduced by periodic and systematic movements.

In the present paper, we propose a concept of the rhythm-based rehabilitation method and explore the design principle focusing on subjects’ individual internal rhythms. As a pilot experiment, we investigate the effect of the external sound that is provided by musical instruments with a certain tempo and evaluate the performance time and subjective feelings during the task. We hypothesize that a mismatch between the external rhythm and the internal rhythm (from synergy between bodily constraints and the nervous control) cause a feeling of discomfort and a declination in the performance.

![Figure 1. A conceptualization of the robotic rehabilitation device. (a) Children with CP sit at the table and handle the device, which is connected to a portable PC for task presentation, recording of behavioral data and communicating with physiotherapists in the hospital. (b) A possible effect of rehabilitation through the rhythm-based device focusing on the internal rhythm generation [Wagatsuma et al., 2012].](image)

2. PROTOTYPE TAPPING DEVICE

We designed a prototype of the tapping device for children with CP (Fig. 2). This device is inspired by the conventional reaching task for rehabilitation of hand movements, in which the children attempt to touch a far target position with their own hands, especially on the paralyzed side. This type of training is necessary to develop not only motor skills but also cognitive abilities, given that some children may have a deficit in a sense of the cognitive field, which may be caused by damage in the parietal lobe of the brain.

By using this device, memory tasks can be provided to set the flashing time to less than 100ms, which is considered to be an upper bound of the reaction time for normal subjects. Subjects had to memorize which button from five was flashed, as a short-term memory task. As they respond, the pushed button flashes again if it is the right choice. We set the memory and reaction task as shown in Fig. 3, and prepared a mechanical metronome (instead of musical instruments) in order to provide a simple external tempo to the subject during the task. As the task condition, we selected three tempos according to results of the preliminary experiment. Music therapy has a long history, and is ongoing on an empirical basis. Recently, a neuroscientific study has reported effects in the treatment of non-fluent aphasia [Tomaino, 2012], though it is still difficult to connect directly to physical therapy procedures. Here we simply used “Presto” as the fastest tempo, “Allegro” as the moderate and “Allegretto” as the slowest. The difference in interval time between the three tempos is approximately 100ms, which is similar to the flashing time and the fastest condition of the waiting time, w1. In the preliminary data, feelings of discomfort were reported when the external tempo was slightly slower (about 100ms) than the condition at which the subject exhibited the best performance. Thus, we investigated the correlation between the performance and arising unpleasant sensations.

3. EXPERIMENTAL RESULTS

According to the experimental design shown in Fig. 3, six normal subjects in their mid-twenties participated in the memory and reaction task. In the task, the next flashing position is determined by the random variable with uniform distribution from the four positions (minus the current position). Prior to the experiment, the researcher provided the subject with the following instructions: 1) let push the flashed button at a short...
moment, 2) the next button will not flash until push the button, 3) task conditions and the sequential order are designed to be a set of [NS, PR, AR, ATT, PR, NS] and perform twice (Fig. 3) and 4) answer the questionnaire to ask the task difficulty in each tempo condition with 1-5 grades and feelings in the free-answer section. In this task, we do not provide any rewards and instructions to speed up operations, because we attempt to observe self-paced motion generations.

Figure 2. The prototype of the tapping device with five palm-sized buttons. (a) Specifications and requirements for the device [cm]. This size reflects the physiotherapist’s experience of rehabilitation for children with CP. (b) Our tapping device and its usage. This prototype is connected to the Arduino microprocessor board for controlling flashing positions and timing, and the PC monitors record the reaction time. The mechanical metronome is used for providing the external tempo.

Figure 3. Task design of the memory and reaction task. After each reaction, a new button is randomly selected and the light embedded in the button will flash after the waiting time, w1, which is prepared as 100ms and 500ms. NS denotes “No sound”; other abbreviations are shown in Table 1.

Table 1. External tempos provided in the memory and reaction task. The mechanical metronome (Fig. 2b) is used and set to one of the following three tempos. Note that beat per minute (bpm) can be converted to interval time [s]. We selected the three tempos according to results of the preliminary experiment.

<table>
<thead>
<tr>
<th>Tempo</th>
<th>BPM</th>
<th>Interval (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presto (PR)</td>
<td>184</td>
<td>0.326</td>
</tr>
<tr>
<td>Allegro (AR)</td>
<td>132</td>
<td>0.455</td>
</tr>
<tr>
<td>Allegretto (ATT)</td>
<td>108</td>
<td>0.556</td>
</tr>
</tbody>
</table>

Experimental results are shown in Fig. 4. In the easier condition (w1 = 500ms), the average declines according to the session number, which simply indicates a habituation or learning effect; the result is not influenced by the external tempo. There are identical “no-sound” condition (NS) at the beginning and the end; however, the total reaction time is significantly different between the two conditions. On the other hand, in the difficult condition (w1 = 100ms), there is no simple habituation and adaptation, and the two “Presto” conditions (PR), which are averages over sessions #4-6 and over sessions #13-15, demonstrated better performances than in the NS conditions. In the time series, this trend increases in the moderate condition (AR) and goes down again in the slow tempo condition (ATT). Interestingly, the score of how difficult the task condition is, which means a subjective feeling of easiness, represents a similar trend to the result with
$w_1 = 100\text{ms}$. According to the detailed interview, most subjects answered that the AR condition is the most difficult case even in the easier condition ($w_1 = 500\text{ms}$), showing a clear habituation.

**Figure 4.** Experimental results of the memory and reaction task with and without sounds of the mechanical metronome. (a) Average data over all subjects in $w_1=500\text{ms}$ condition. (b) Average data over all subjects in $w_1=100\text{ms}$ condition. (c) Results of scores of the task difficulty (1: easy - 5: difficult) obtained from questionnaire sheets. Tasks were done separately in $w_1$.

### 4. CONCLUSIONS

We designed a prototype of a tapping device for children with CP. It is expected to be used instead of the conventional reaching task for rehabilitation of hand movements, especially on the paralyzed side, and extend to the rhythm-based rehabilitation tool. We found that a misalignment of the pacemaker with the personally comfortable tempo brings subjects a feeling of discomfort and declination of the performance if the task is in a rushed condition ($w_1 = 100\text{ms}$). In addition, this result is consistent with the subjective feeling of how difficult the task is. This result suggests that a self-motivated rhythm is more disturbed by a slightly slow rhythm (about 100ms) than by the fastest one. Effectiveness of motor learning clearly appears in the condition of $w_1 = 500\text{ms}$ (Fig. 4a), which occurs independent from the change of external tempo, even though the subjective feeling is the same as the 100ms condition. This fact suggests that motor learning or habituation is enhanced with/without external tempos in a range of the slow reaction. Therefore, a possible contribution of the external tempo is expected in the range of the limitations of the reaction time, approximately 0.1s, which might be related to the encoding time scale of the short-term memory. This is an important step towards developing a rhythm-based rehabilitation method and a design principle focusing on subjects’ individual internal rhythms.

**Acknowledgements:** This work is partially supported by JSPS KAKENHI (22300081).

### 5. REFERENCES


