

The development of the Postural Control Support System and the Multilocomotor

Junichi Takashio*, Biwako Gakuen Medical and Welfare Center, Kusatsu

Masao Kumode, Biwako Gakuen Medical and Welfare Center, Kusatsu

Ichiro Uchiyama, Department of Psychology, Doshisha University

Joseph J. Campos, Institute of Human Development, University of California, Berkeley

David I. Anderson, Development of Kinesiology, San Francisco State University

Abstract

Ten percent of babies with a low birth weight less than 1,000 grams are diagnosed as having cerebral palsy. These babies have to start life with difficulties in both motor and cognitive development due to periventricular leukomalacia (PVL), intracranial hemorrhage and so forth. It is very difficult to predict their prognosis since damage to each child's central nervous system is different. And many researchers point out the limitations of the effects of physical therapy alone. However, some children with level 4 and 5 on the Gross Motor Function Classification System^[1] can develop physical function by applying support techniques in early stages to the degree in which they can move without the help of others. One recent case involved a small child who is unable to maintain antigravity head and trunk posture when lying on her stomach (prone position) and sitting. She has also spasms in her lower limbs and difficulty with motor function of both upper limbs. I will report about a process I developed, the "Postural Control Support System," which helps the girl to maintain posture and "Multilocomotor" which helps her to move.

1. Introduction

Cerebral palsy is not a term for a single disorder but a term that describes multiple neurological damage that causes developmental abnormality in motor function and postural control. It is defined as a general term for a syndrome of nonprogressive impaired motor function caused by brain damage or a defect whose clinical presentation frequently changes. This definition has gained a broad consensus.^[2]

*Junichi Takashio, PT, Department of Rehabilitation, Biwakogakuen Medical and Welfare Center, Kusatsu, 3-113, 8-chome Kasayama Kusatsu, Shiga, 525-0072 JAPAN
Phone/Fax +81-77-566-0709, j_takashio@biwakogakuen.or.jp

In 2004, an international workshop on the definition and classification of cerebral palsy was held in Bethesda, Maryland in the U.S.A., where participants concluded that the most up-to-date assessment of a definition and classification of cerebral palsy in light of understanding of neurobiology and the conception of functional status and participation is urgently needed. [3]

On the other hand, Mayston, M., a director of the Bobath Centre in London noted “Physical therapy is considered to play an important role for management of children with cerebral palsy. However, what kind of physical therapy, how long and how intently children should undergo it is a difficult question. Approaches of so-called methods are often subject to criticism due to lack of scientific basis and evidence of their effect. Any specific approach lacks valid evidence of its effects and there is also no approach with evident validity sufficient to demonstrate a significant advantage over another.” [4]

The revision of the Medical Service Law in April 2006 in Japan requests therapists to apply evidence-based intervention. However, there is no evidence to help the therapists to meet that request. Despite recent evidence that supports muscle strength therapy, Constraint-induced movement therapy^[5], conductive education and so forth, it doesn't justify immediate application of these methods to all of the children with cerebral palsy. Especially children classified level 4 and 5 on the Gross Motor Function Classification System seem to have difficulty adapting to the environment. In his books^[6,7], Imagawa urges all of us who are involved with children with a handicap to courageously promote a paradigm shift without being constrained by past context.

Scherzer, A. noted in “Early Diagnosis and Interventional Therapy in Cerebral Palsy”^[8] that it is more appropriate to perceive cerebral palsy as a developmental disorder than as the impaired states of muscle and bone structures. Cognitive development with respect to child development has begun to be understood scientifically in just the last ten years. Meanwhile, researchers have found that physical development and psychological development are mutually related and the child's experiences in early stages will influence all of later behavior. One or more limitations, retardations and disorders in the development of motor function, cognition, sociality and emotion causes adverse effects in other areas of development. Motor function rapidly develops in the first three years of life and it is a child's first means of acquiring learning and social skills, which then cultivates language ability and independence. Through experiences of motor interaction, infants learn about things and people around them and cause and

effect. Infants generate their experiences or participate in what happens around them actively rather than accepting them passively. Infants with cerebral palsy often lack the ability to move, manipulate things and speak, which are vital to having and interest in the environment and taking the initiative to act on it. This is a big obstacle to learning. They miss many opportunities to learn, and tend to give up controlling the world around them and feel powerlessness after they know they cannot work on, change or influence the environment.^[9] Thinking that they cannot do anything, they come to have a negative identity and give up trying to explore and deal with their world after repeated failure.^[10] This feeling of helplessness is said to be established before the age of four. ^[11, 12]

In Japan, current treatment for children with cerebral palsy is mainly rehabilitation following standard medical models applied to the health system. In addition, support is provided in places far from the children's daily environment such as in hospitals and institutions. Therefore, considerable treatment time tends to be spent on existing therapies without trying any new ones.

2. Causes of cerebral palsy

Formerly, the three major causes of cerebral palsy were asphyxia neonatorum, low birth weight and kernicterus. Though kernicterus has now become a rare disease, hypoxic-ischemic encephalopathy that accompanies asphyxia, low birth weight and periventricular leukomalacia of preterm infants have come to be considered to be major causes of cerebral palsy.

According to the National Institute of Neurological Disorders and Stroke ^[13,14] in the U.S., hypoxic-ischemic encephalopathy caused by asphyxia accounts for only around 10 percent of causes of cerebral palsy. Cerebral palsy is mainly due to causes other than hypoxic-ischemic encephalopathy that accompanies asphyxia neonatorum.

PVL is frequently seen as a symptom of a brain disorder that occurs in preterm infants who were born before 32 weeks of gestation. It is responsible for cerebral palsy in low birth weight infants who were born preterm. Since preterm babies were born when their cerebral blood vessels and glia formation were still immature, decreased blood flow in their brain is likely to cause PVL. It occurs more commonly in periventricular white matter that is from the triangular part to the retro horn of the lateral ventricle.

Since the areas where PVL are commonly found includes the sensory nerve that ascends from the spinal cord to the sensorial area of the cerebral cortex and the pyramidal tract that passes down from the cerebral cortex to the spinal cord, PVL often causes sensory impairment and spasticity. Of the cerebral palsy caused by PVL, spastic quadriplegia is the most common condition however, retardation of psychological development of children with CP caused by PVL is less severe than in children with CP caused by hypoxic-ischemic encephalopathy. Especially some children with spastic quadriplegia do not have any signs of mental retardation. However, among the cases of children with quadriplegia, moderate to severe mental retardation is often seen. Furthermore, some also have epilepsy such as West syndrome, visuospatial agnosia and learning disability. In a case of PVL, three hours after a cerebral blood decrease, ischemic coagulation necrosis occurs. Three hours to 24 hours after ischemic coagulation necrosis, the microglial cell is activated. On the second day, axonal degeneration occurs around necrotic focus. On the third to fifth day, lipid macrophage appears with reactive astroglia and neoangiogenesis follows. On the 13th to 14th day, cavity formation is observed.

3. Development of children with disability

Hypertonus, abnormal motor development and so forth severely prevent children with postural control from using the parts of the body for load bearing and maintaining posture, which limits their motion. These obstacles have also adverse effects on the ability to nurture interaction with the environment. Impairment of motion limits the areas in which they can move around. And as these obstacles are passively accepted, there is the likelihood that they and people around them give up on their functionality and social participation. In order to avoid such situations, management of children's life and rehabilitation as a treatment from the early stages are essential.

3-1. Imbalance of immaturity in the nerve system

Nonprogressive disability of the central nervous system has an effect on the brain stem, which then causes abnormal postural tone (both hypertonus and hypotonus). Remaining pathological reflex and primitive reflexes prevent children from developing postural control and motor control, furthermore often creating uniform postural movement patterns, which undermine motor diversity that children with no disability acquire in their development. It also undermines the integration of senses (visual sense, vestibular sense, somatic sense) that could have been integrated through the developing

of motor diversity. There is the likelihood that motor function and reception of sensible stimulus are equally disrupted by the disability. These disabilities appear in various manners, and imbalance of developments is also frequently observed. Even though children respond well to situations around them, their responsive expression is often so weak or is likely to resemble their motor patterns that it is difficult for people around them to understand the child's responses. Children have a certain level of ability. However their ability cannot pass through a normal series of developmental stages. Regardless of the seriousness of disability, some children can develop as time passes, but retrograde development also sometimes occurs.

3-2. Effects of abnormal muscle tone

Hypotonic muscle tone and hyper muscle tone children show in their daily life often upset their family members. As their posture is unsteady, picking them up is difficult. And keeping their posture in various manners is also difficult. As children grow up, abnormal muscle tone furthers the limitation of muscle motor function and joint mobility, which sometime result in structural deformation of the body.

3-3. Sensory impairment and function

Regarding problems in sensors, visual sensation, auditory sensation, somatic sensation and so forth are impaired singly or redundantly in some cases. As for visual impairments, there are peripheral defect, cataract, structural visual impairment such as inherited glaucoma, and visual defect of central origin related to the problem of optic tract or visual cortex. Defect of optic coordinated movement causes problems of space perception by visual sensation. Auditory impairment is related complicatedly to defects of central origin including conductive and sensorineural impairment and problem of acoustic pathway. Regarding tactile sensibility, selective activation of afferent fibers (the inhibitory effects of nociceptors or mechanoreceptors) remains immature and excessive self-defense response to dual tactile stimulation continues, which hinders not only sensory systematization but also information processing of deep sense, space recognition and so forth that are indispensable for recognition of right and left or acquisition of directionality. As a result of these difficulties, children with cerebral palsy cannot establish the body schema.

3-4. Sensory abnormal movement pattern and movement restrictions

Abnormality of self-initiated movement and postural movement pattern caused by nerve damage in early developmental stages will become a serious limiting factor in

later development and prevent children from interacting with the environment and generating their experiences or participation in what would happen around them actively. Therefore until they become old enough to interact with others voluntarily, they are likely to be passive and dependent. In this way, children with cerebral palsy are forced to lead everyday life with both physical and mental problems.

4. Theoretical background of equipment development

4-1. Development of postural control

According to Pountney, T. E. and others, development of postural control is the process of acquiring the ability to change areas of load bearing ^[15]. In other words, the mechanism of postural control in the central nervous system is defined as developing by using appropriate areas of load bearing. However, for children with cerebral palsy, it is difficult to use these areas in an appropriate manner.

4-2. Development of body as a structure

To develop, children need to adapt to their environment including people in the most appropriate way. In other words, development can take place when children's ability including functional disability, the environment fit well adaptive behaviors in a voluntary way. Thinking of development as a structure, advice from the perspective of development in a constructive manner would increase in importance. In the fourth annual conference of the Japanese Society of Baby Science, Yasuo Kuniyoshi suggested in his presentation on "Trial of modeling of prenatal program and early cognitive development based on configuration logic." ^[16] that a highly simple learning system has the possibility to enable fetuses to acquire higher cognitive abilities through experience of sensory-motor. His result was based on the idea that information input of fetuses through their activities in the womb is making up their brain, which is supported by robotic and calculating simulation.

Connecting two objects moving in a chaotic pattern with one belt can reduce their irregular movements, and then adding two belts to make three can reduce the irregularity further. In other words, by externally supporting the spinal column and muscles of children with cerebral palsy who cannot control two objects, namely, their bosom and pelvic band that comprise upper body, it becomes possible for them to learn postural control through information from the body and environment. This idea was suggested to us from the abovementioned presentation by Kuniyoshi.

4-3. Cognitive development

Campos, J.J. states in his presentation “Babies’ motor experiences construct the cognitive world” ^[17] in the second annual conference of the New Japanese Society of Baby Science that appearance of crawling, the movement which is integrated in the genome and appears at seven or eight months of age, varies depending on babies’ birth month, climate, location, and parents’ habit of child-rearing. Babies who were born in summer begin to crawl three weeks later than babies born in winter since the season when they are supposed to start crawling happens to be winter. And in the United State, mothers have been recommended to lay babies in their back to prevent Sudden Infant Death Syndrome since 1995, which delays the appearance of crawling for one month. He emphasized the importance of environmental factors to development giving those examples and pointed out the abilities babies can acquire by crawling, the motor experience, as follows. 1) space orientation 2) finding the things that are hidden 3) looking in the direction that other people point to or look at 4) postural control by vision 5) fear of heights. These are the result of cognitive developments which crawling promotes. In addition to enhancement of babies’ ability to control of their posture, crawling increases visual information ^[18], social reference, emotional communication and then promotes cognitive development. By enabling them to move around with some equipment, babies who have difficulty with motor function could raise the frequency rate which measures how often they look in the direction one points to or looks at from 12 percent to 50 percent What changes babies’ behavior are their experiences, not their age. Though motor experiences per se facilitate development, they do not cause development, . Enabling children who cannot move by themselves to begin to have motor experiences at the same time as other children is also important to promote formation of the neural network

Butler, C. noted that even 20 to 36 month-old infants with motor disability may achieve self-mobility with the help of electrical movement support equipment ^[19--22], which improves their independence, eases the feeling of helplessness, and increases the chances to improve their sociality, emotion and cognitive development. He also reported that children’s acquiring self-mobility resulted in satisfaction and positive psychological good effects in the parents. He said also “the decision to use the movement support equipment did not disturb the possibility of children’s motor development and children did not give up walking without it even after starting to use the alternative means”.

5. Process of the development of the equipment

5-1. Research in CanChild

The Gross Motor Function Classification System for Cerebral Palsy (GMFCS) was developed by CanChild Center for Childhood Disability Research, McMaster University, Canada [23]. It classifies the level of disability into 5 levels depending on self-initiated movement (I being least serious and V the most serious). Children classified level V are described as follows: they have difficulty moving by themselves even with support equipment (electronic chair, environment control equipment and so forth). “Physical impairments restrict voluntary control of movement and the ability to maintain antigravity head and trunk postures. All areas of motor function are limited. Functional limitations in sitting and standing are not fully compensated for through the use of adaptive equipment and assistive technology. At level V, children have no means of independent mobility and are transported. Some children achieve self-mobility using a power wheelchair with extensive adaptations. Children in Level V lack independence even in basic antigravity postural control. Self-mobility is achieved only if the child can learn how to operate an electrically powered wheelchair.”

5-2. Profile of Runa

Runa was born 730g on July 22, 2001, at preterm, 26 weeks of gestation due to threatened premature delivery. At the age of 7 months and 2 weeks (4 months if she had been born at fullterm), she had no abnormal EEG (electroencephalogram). Since dilatation and shape anomaly of the ventricles was observed by MRI and it might have lead to PVL, she was provided referral to our hospital. Currently she is 5, her GMFCS level is V, function of superior limb is classified level IV on the Bimanual Fine Motor Function (BFMF).

April 17, 2002, she started physical treatment. We summarized early assessment of her condition and established a goal of therapy. When lying on her back (spinal position), she could not adjust timings of postural control and motor control due to tonic neck reflex. She chose to use extensor muscle when she tried to move. Her neck control was not sufficient and both her arm and leg were highly tense. She has not established the schema (basic pattern of action) of her lower limb yet. We set a goal as follows 1) to enhance awareness of the body by promoting the establishment of the schema of her lower limb. 2) to acquire the effectiveness of upper limb.



[One year and 6 months, head is supported with neck roll]

Her postural tonic muscle was still weak and could not maintain a sitting posture even after she became two years old. However, since her desire to interact with her environment was growing, the gap between her desire to move and her actual motor function was also increasing. Therefore we fixed her trunk as a compensatory approach and she tended to maintain her posture. In that manner, we continued to try to enhance her antigravity postural control to increase trunk activity. However, in addition to her easy fatigability, maladaptive response increased, which disturbed the relationship with us, therapists. We felt that we had reached the limit of our intervention by applying existing therapies. We reviewed them and reconstructed our approach considering her disability as an adaptive disability to environment. We thought that gravity influences her and came up with the idea that she might have motor experience if she could reduce the gravity on her body, through which she could obtain and deal with information for balancing from the soles of her feet. Since physical assistance has its limitation in terms of self-initiated movement, we tried first to have her use Johnny jump-up made by EVENFLO Co., which suspends the infant's body. However, we gave up using it due to its limitation in the usage environment.

As a result of the above failure, we decided to develop equipment, Postural control support system (PCSS) for body weight and postural control, and Multilocomotor.



[2 years and 8 months, playing with Johnny jump-up]

6. Postural Control Support System

6-1. Structure and characteristics

PCSS is composed of a unit that supports the pelvic band and a unit that supports chest. Each unit is connected by a flat spring and two belts placed on both sides of the flat spring. PCSS is fastened to the body through a joint. This mechanism functions as resilience in case the body collapses laterally, leading to help its recovery reactions. Reducing the weight burden with this unit and body makes it possible to receive sense information from soles of the feet without anxiety. This will lead to curb the increase of lower limb tensions and enable controlling exercise. To allow this to happen, we set up a 4-node-link structure and inclusion gas damper. Unlike the body trunk corset and Hart Walker, which have already been used, the PCSS, by aiding the body's recovery required for learning PCSS, allowed actions that therapists have carried out as handling. In handling, in which the therapist's hands feel child move and control the movement through their own central nervous system, these movements are sometimes stopped or their direction changed. Without constant order, children cannot learn to control their posture or moves by themselves. Considering this, we will find there will be a big difference in curative effects. However, PCSS' control system, consisting only of a flat spring and elastic band, is so simple that certain reactions to the child's movement can be anticipated. Feedback or a feed forward system^[24] based on error information, deemed as a learning model central nervous system, can be vitalized.



[PCSS front]



[PCSS back]

6-2 Development process of PCSS

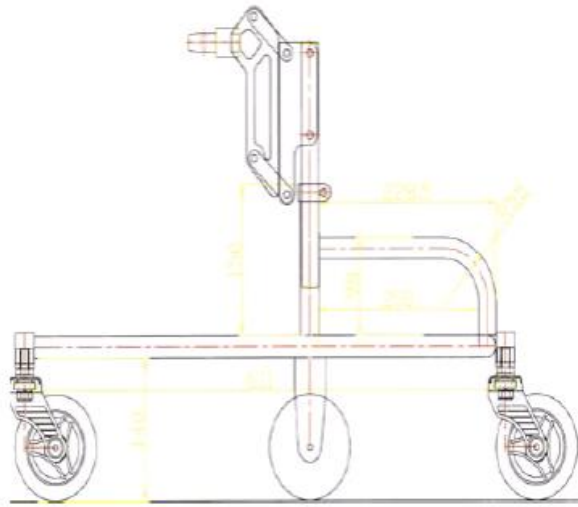
In the original PCSS unit part, as a pair of the right and left belt protruded from the unit link, recovery power was not sufficient against lateral collapse. Also, due to the insufficient structural strength of the pelvic band unit link, gas dampers came loose without achieving effect as suspensions.



[PCSS with 4 rings]



[PCSS with 4 rings, rear]



[Blueprint of PCSS driving unit]



[Fastening front control belt to PCSS unit]



[PC mouse operation putting on PCSS]



[Jointing section]



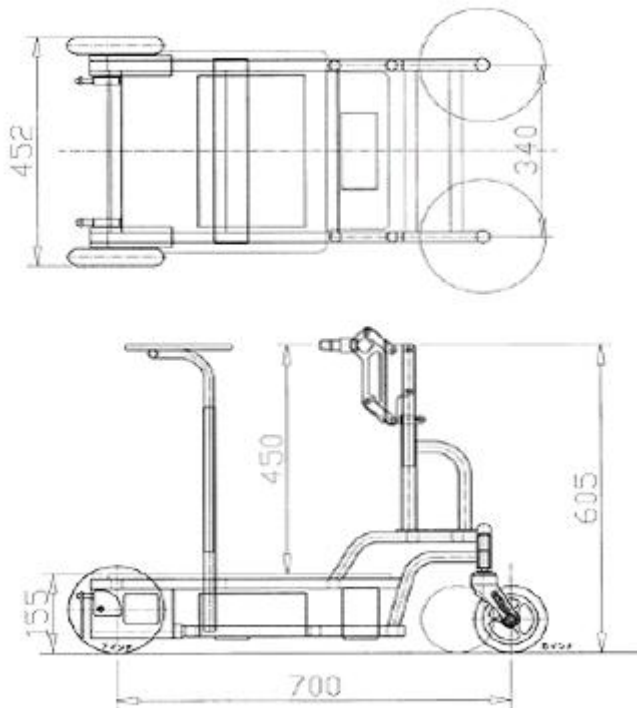
[Completed PCSS]

She uses PCSS also at home and prefers using PCSS with the Multilocomotor

7. Process of developing the Multilocomotor

The Multilocomotor was developed in order to enable a child whose posture is supported by PCSS to move by herself. At the beginning, we developed it using YAMAHA JW-2, an electric unit available on the market. However, it turned out unusable due to its drive-line being too big in addition to its lack of a speed adjusting function for low speed. In developing the next one, our previous failure was reviewed on the premise that the drive-line, control system, battery, etc., could be made more compact as a high priority improvement. As a result, we decided to use an electric unit made by Arizono Orthopedic Supplies Co. whose speed (going forward, back and turning) is controlled in range of 0 - 1km/h in a single step. Its starting impact is also small.

The Multilocomotor is 700 mm long, 452 mm wide, 400 mm high and weighs 24 kg, relatively compact as a trial model, which makes it possible to use it not only at the home but also outside for various purposes.



[Blueprint of the Multilocomotor]



[Various kinds of controllers]

As she could not touch metallic levers due to dysesthesia (primary sense), we took measures to wrap them with wool or to cover them with plastic caps.

8. Process of acquiring experiences of moving with the Multilocomotor

Consideration was given to let the child experience new things with the Multilocomotor.

1) Until she understood that the Multilocomotor has the same structure as the PCSS and the way she could support her posture with it is also the same, we kept her from using the electric unit. So she learned through repeatedly playing with the equipment that, with the exception of the electric unit, the PCSS and the Multilocomotor are basically the same.

2) In order to help her deepen her understanding of the cause and effect of operating the Multilocomotor, we encouraged her to use a PC with a mouse at home.

3) Her skill in using the controller of the Multilocomotor improved by instruction from adults, through which she became to be able to predict what would happen as the result of her own movements based on visual information.

4) Use of the Multilocomotor was limited to 40 minutes, once a week. Three sessions were given from the introduction period to the controlling period.



[She began using the Multilocomotor]



[Playing this game with the Multilocomotor]



[PC operation with the Multilocomotor]



[She began using the Multilocomotor]

8-1 Process of acquired experience of movement

When she used the controller of the Multilocomotor for the first time she made a surprising facial expression when she felt her posture had changed unexpectedly due to its movements. However, she soon seemed to feel secure and her emotional stability was not disrupted since she knew that she was controlling the Multilocomotor which is basically the same as the PCSS.

Later she began to notice that her environment was changing due to her own control. As she improved her skill to control she came to prefer going to the corner of the room. It is believed that she was making a map in her mind by moving around the room. The same behavior is often seen when children with moving difficulties came to be able to move around. She began to show an interest in the concept of height when looking at a shelf against the wall.

Session 1.

Unintentionally touching the controller while playing quoits prompted her initial operation.



[This is fun!]



[Look, I can move! (Empathy)]

Session 10.

Changing the lever to cross shape made the controller easier to use. Since the metal lever was slippery, we wound yarn around it.



[Move forward by pushing the lever]



[Watch me!]

Session 16.

She looks straight at a stationary object and estimates the distance from her and thinks about the relation between each thing. Both cognitive and emotional development began to be seen, her facial expression became vivid and varied. The number of times she looks behind was increasing. She seemed to be curious about what was happening behind her.



[Moving with Multilocomotor]



[She is looking into the staff room]

She noticed an elephant sticker on the locker and moved around in front of it. We were moved by the way she noticed very small things and events that adults would miss. Children have their own world.



[She found an elephant seal on the rocker]



[Moving forward and back]

8-2. Improvement of the Multilocomotor's controller

Dr. Campos advised us to give her a rest every 8 to 10 minutes during the training, considering her physical strength and to improve the switch to touch type during his visit to Biwako Gakuen Medical and Welfare Center.



[The Multilocomotor touch switchboard] [She is practicing the touch switch]

She is now going to nursery school in her neighborhood and improving adaptability to her environment. Her nursery school teachers reported that though the number of her words is still limited to such as “Mom, take, bye-bye, etc., she is trying to call her teachers and friends. At our institute, Biwako Gakuen Medical and Welfare Center, she shows her gratitude to us by making a sign with her palm together in front of her chest when the training is over. And recently she came to enjoy saying “bye-bye” to people who pass by when leaving the rehabilitation room to the corridor. Though her adaptability to the environment is still not adequate, we would feel pleased if we could help her expand the possibilities of adaptation to the environment ^[25].

9. Conclusion

For children’s development, the role of experience of locomotion in the early stages is very important. However, there are children who are unable to experience locomotion due to serious motor impairment. How do they see and feel the world around them, when their environment, in most cases, has a one-sided influence on them? Under unchanged conditions in which they have always been helped to do everything in daily life from the early stages, eventually they tend to become passive and lose their capability and independence. There is a high likelihood that these situations make it difficult for them to communicate with others or participate in society on their own initiative.

Beckung, E. surveyed 176 children with cerebral palsy between the ages of 5 and 8 and revealed the relation between nerve damage and limitation of activities and participation. There turned out to be a high correlation between the level of GMFCS and the level of Bimanual Fine Motor Function (BFMF). In the case of level V on GMFCS, a little less than 80 percent of the children have moderate difficulty or severe difficulty with motor function. Regarding education, almost all of them have serious situations. As for social limitations, 10 percent of the children have moderate impairments. In the case of level IV on BFMF, 66 percent of the children have a severe problem and 10 percent of the children have a moderate problem with motor function. As for education, 33 percent have a moderate problem. And as for social limitations, difficulty was recognized at all levels^[26], which suggests the possibility that the conditions of social participation of children with severe motor difficulty could be improved.

However, in Japan, powered wheelchairs are provided by public subscription only after children become seven. In addition to that, the decision to provide those cannot be made if a child does not have the ability to control it safely. In other words, unless parents buy it themselves, it is actually impossible to introduce it to a child in the early developmental stages. Does the fact that there is no system to provide wheelchairs to children while they are very small mean that no one feels the necessity to provide them to small children? While training the children to use the PCSS and the Multilocomotor which we developed for children with cerebral palsy, we often witnessed children taking the initiative to interact with their environment. In this era of rapid progress in brain science, robotics and so forth, we are very eager for help from the participants in this conference, the Japanese Society of Baby Science, to develop equipment that enables children with motor difficulties to move by themselves and enjoy interacting with their environment.

Acknowledgements

We would like to express our heartfelt gratitude to Francebed Medical Home Care Research Subsidy Foundation for their providing research grants to develop equipment and to Runa and her parents; they are our research partners.

We posted photographs and the names of our collaborators on the paper after getting permission from them and their parents in accordance with the Private Information

Reference

- [1] Palisano, R. et al : Development of validation of a gross motor function classification system for children with cerebral palsy. *Developmental Medicine & Child Neurology* 39,214-223, (1997).
- [2] Mutch, L., Alberman, E., Hagberg, B., Kodama, K., Perat, M.V. : Cerebral palsy epidemiology: where are we now and where are we going? . *Developmental Medicine & Child Neurology* 34,547-551, (1992).
- [3] <http://www.castangfoundation.net/home.asp>
- [4] Mayston, M. : Evidence-based physical therapy for the management of children with cerebral palsy. *Developmental Medicine & Child Neurology*, 47, 795-795, (2005).
- [5] Charles, J.R. : Efficacy of a child-friendly form of constraint-induced movement therapy in hemiplegic cerebral palsy: a randomized control trial. *Developmental Medicine & Child Neurology* 48,635-42, (2006).
- [6] Imagawa, I. : Hattatsu shougaiji no atarashii ryouiku. Miwa Shoten (2000).
- [7] Ketelaar, M. : Children with cerebral palsy: A functional approach to physical therapy. Eburon Academic Publishers, (1999).
- [8] Scherzer, A. : Early Diagnosis and Interventional Therapy in Cerebral Palsy: An Interdisciplinary Age-Focused Approach, third edition. Marcel Dekker, (2001).
- [9] Rosenbloom, L. : Consequences of impaired movement: A hypothesis and review. In: Holt KS, ed. *Movement and Child Development*. Philadelphia: Lippincott, 159-162, (1975).
- [10] Lewis, M. : Perceptual-cognitive development in infancy: A generalized expectancy model as a function of the mother-infant interaction. *Merrill-Palmer Q* 81-100, (1969).
- [11] Harter, S. : Effectance motivation revisited: Toward a developmental model. *Human Development* 34-64, (1978).
- [12] Safford, P. : *Developmental Intervention with Young Physically Handicapped Children*. Springfield, IL: Chaeles C Thomas, (1975).
- [13] <http://www.ninds.nih.gov/index.htm>
- [14] <http://www.twinenterprises.com/cp/>
- [15] Pountney ,T.E. : Early developmental of postural control. *Physiotherapy* 799-802 (1990).
- [16] Kuniyoshi, Y. : “Trial of modeling of prenatal program and early cognitive development based on configuration logic”. The fourth annual conference of the Japanese Society of Baby Science (2004).

- [17] Campos, J.J. : “Babies’ motor experiences construct the cognitive world”. The second annual conference of the New Japanese Society of Baby Science (2003)
- [18] Campos, J.J. Uchiyama, I. : Responsiveness to terrestrial optic flow in infancy: does locomotor experience play a role? *Human Movement Science*. 4-17, (2006).
- [19] Butler, C. : Effects of powered mobility on self-initiated behaviors of very young children with locomotor disability *Developmental Medicine & Child Neurology*, 325-32, (1986).
- [20] Butler, C. : Powered mobility for very young disabled children. *Developmental Medicine & Child Neurology*, 472-474, (1983).
- [21] Butler, C. : Effects of powered mobility on self-initiated behaviors of very young children with locomotor disability. *Developmental Medicine & Child Neurology*, 325-332, (1986).
- [22] Tefft, D. : Cognitive predictors of young children's readiness for powered mobility. *Developmental Medicine & Child Neurology*, 665-670, (1999).
- [23] <http://www.canchild.ca/Default.aspx?tabid=36>
- [24] Imamizu, H. : Modular organization of internal models of tools in the human cerebellum *Proc Natl Acad Sci U S A*. 5461-5466, (2003).
- [25] Bateson, P. : How do sensitive periods arise and what are they for? *Animal Behaviour*, 470-486, (1979).
- [26] Beckung, E. : Neuroimpairments, activity limitations, and participation restrictions in cerebral palsy. *Developmental Medicine & Child Neurology*, 309-316,(2002).