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# Research Prospects for Controlling the Quiet Standing Posture: Discussion for the Creation of New Research Findings for People with Cerebral Palsy

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Abstract: Humans adopt postures and move while being affected by Earth's gravity. Adopting and controlling a standing posture in particular involves extremely complex adjustments to balance. In addition, people with cerebral palsy often have difficulty maintaining a standing posture. The aim of this paper was to discuss the acquisition of new research findings regarding standing postural control in people with cerebral palsy through insights into research findings that reveal how humans control a static standing posture. To achieve the goal, this paper discusses the historical development of research on standing postural control and prospects for its future. This paper also reviews research on standing postural control in people with cerebral palsy and prospects for the future. In summary, the process by which people with cerebral palsy master standing postural control needs to be painstakingly identified, and reorganization of postural control in those people needs to be examined.

Key words: a people with cerebral palsy, quiet standing, body sway

## 1. Introduction

For organisms that live on Earth, gravity is an environmental factor they cannot "ignore." That said, gravity does not simply "bear down" on the organisms that live here. We learn to adopt various postures and perform various movements as we develop and our brain functions mature. Through this process, we gradually adapt to a gravitational environment. However, a major hurdle in that process is undoubtedly attaining a static standing posture (denoted here as "a standing position"). Compared to other mammals that adopt a quadrupedal posture, humans have a small base of support and a high center of gravity, so they need advanced postural control (Itaya, 2015). Typically developing infants attain a standing position at about 12 months. This is the result of a relentless challenge posed by gravity that the Earth's environment has imposed on humans over the course of recorded history.

That said, adapting to gravity, as was mentioned earlier, and attaining a standing position in particular is a major hurdle that awaits people with cerebral palsy. Such people often have issues with sensation, recognition, and communication in addition to delayed or aberrant motor and postural development associated with brain lesions (Bax, Goldstein, Rosenbaum, Leviton, Paneth, Dan, Jacobsson, Damiano, 2005). Human postural control is achieved when visual, somatosensory, and vestibular sensory input are combined by the central nervous system, creating various feedback loops (Shumway-

Cook, Woollacott, 2000). Typically developing people develop a basis for adopting postures through repeated physical activities from the fetal stage to infancy. In contrast, people with cerebral palsy must adopt postures while dealing with obstacles arising in early development. Some people with cerebral palsy are able to stand or walk, but they continue to adopt compensatory postural control strategies. This can lead to an imbalance in muscle activity and problems such as joint contractures and lower back pain (Kusumoto, Nitta, Matsuda, 2014).

These problems are directly linked to quality of life (QoL) for people with cerebral palsy. In light of the current state of research in related areas, the discussion of these problems has certainly been limited. Of course, numerous studies on body sway while standing have been conducted in areas such as rehabilitation medicine, physical therapy, and sports science in Japan alone (e.g. Fujiwara and Inoue, 1981; Hiiragi, 2008; Mochizuki and Kaneko, 2009; Itaya, 2015; Asai, 2019). What has become apparent from a series of studies is that the factors governing a standing posture in humans are extremely varied. Future studies need to ask "How is a standing posture governed by given factors?" and "What factors hamper the control of a standing posture?" In light of these points, this paper surveys research on the control of a standing posture and it discusses underlying factors that hamper standing postural control in people with cerebral palsy. In addition, this paper offers insight into future research on people with cerebral palsy through use of "body sway" as an index.

## 2. Research on control of a standing posture: Its historical development

In simple terms, the standing posture of humans is achieved when the line of gravity is within the base of support (BoS) created by the soles of the feet on the floor. A standing posture is stable with "a wide BoS and low center of gravity." This fact is required knowledge, at least in care settings. Nevertheless, people are seldom aware of their BoS or center of gravity in everyday life. The human body is structured with a relatively high center of gravity and a decidedly small area in which the sole contacts the ground. Thus, people use a strategy of "making micro-adjustments" to avoid falls. Rothwell (1994) stated that the standing position in humans consisted of 3 elements: support, stability, and balance. Balance, defined as "the ability to keep the body' s line of gravity within a certain BoS (limits of stability)" (Shumway-Cook and Woollacott, 2000) is the gold standard for measuring body sway, and numerous studies on control of a standing posture have been conducted in the areas of sports science and physical therapy.

An apparatus called a "stabilometer" is used to measure body sway. A subject stands on a platform for a given amount of time, allowing identification of characteristics such as the speed of displacement of the center of gravity and its extent, direction, and frequency.

Looking at history, research on swaying of the body originated with Romberg (1846), who conducted neurological testing to assess damage to the dorsal columns. Later research prior to the early 1900s focused on swaying of the head as an indicator, but research that examined movement of the center of pressure (COP) of the foot, such as that by Thomas and Whitney (1959), increased. In Japan, Hirasawa (1970) put forth the theory of "stasiology." As a result, attempts to ascertain body sway during a standing posture via foot pressure began in the areas of kinesiology, physical therapy, and otolaryngology. Taguchi and Yoda (1976) sought to develop qualitative and quantitative indices of dysequilibrium. In their study, they used equipment to measure body sway in combination with conditions such as "feet apart and feet together" and "eyes opened and eyes closed," and they measured sway path length. In addition, Shirai, Ozawa, Hirata, and Ishikawa (1976) found that the area of body sway clearly increased when not looking at a specific point in comparison to gazing at a fixed point, and they noted the need to keep visual stimuli constant during stabilometry. Later, body sway was standardized in testing to differentiate dizziness and dysequilibrium, and studies on control of a standing posture using a stabilometer were often conducted under the conditions devised by the researchers mentioned earlier.

Afterwards, studies to measure body sway in a standing posture involved “a standing position with the feet spread slightly apart.” Subjects were instructed to “focus on an object 2 m in front while their eyes were opened,” and measurement was performed with the “eyes opened and closed.” A handful of studies used a set “time for measurement of a standing posture (excluding the initial period of excessive swaying) of 30 to 60 seconds” (e.g. Hiiragi, 2008; Yamamoto, 2012). In addition, some studies involved a protocol of moving one’ s center of gravity forwards and backwards or to the right or left, like the study by Mochizuki and Mineshima (2000), while other studies examined postural stability or they measured body sway while standing on one leg (watanabe, 2018). COP is a way of gauging support of the body. COP parameters such as the unit path length (the mean distance of COP displacement), effective sway (variation in the average center of gravity), the area of COP sway, and the velocity of COP displacement have been used as indices of the stability of a standing posture (Benvenuti, 2001). In Japan, use of a stabilometer that complies with Japanese Industrial Standards is highly recommended (Japan Society for Equilibrium Research, 2015). Stabilometers that meet certain criteria for durability, errors in the position of the center of gravity, and their natural frequency are widely available. Such stabilometers are not used for diagnostic purposes. Rather, they are used in areas such as sports science and psychology in, for example, studies examining changes in body sway with age.

In light of the above, most research to ascertain standing postural control in humans uses the amount and area of body sway as indices. In contrast, Mochizuki and Mineshima (2000) stated that “a subject’s actual balance and postural stability often differs from indices used to assess balance with a stabilometer,” and they expressed doubts about assessing balance with only various indices obtained using a stabilometer. Citing the inconsistency in research findings regarding instability in a static standing position in patients with Parkinson’s disease, Nomura (2011) noted that few studies had delved into postural control mechanisms. Noting the lack of previous research on “understanding mechanisms of impairment,” Nomura (2011) also said that creating a model of neural control “that allows firm stabilization of a standing posture while remaining loose” is a topic for the future. Thus, research on control of a standing posture needs to validate a combination of body sway and other indices.

## 3. Control of a standing posture by people with cerebral palsy

There are a number of previous findings with regard to control of a standing posture by healthy people, such as adults in their 30s to 60s (Sumi et al., 1987), adolescents (Hiiragi, 2008), and infants (Murata et al., 2019). In addition, studies have also involved subjects with conditions such as a cerebrovascular disorder or Parkinson’s disease (Mochizuki and Mineshima, 2000). The latter, which include case studies presented at conferences, are too numerous to mention.

Presentations at conferences have reported some findings with regard to body sway in a standing posture of people with cerebral palsy (e.g. Yamamoto et al., 2015), but there are only a handful of studies in journals (Kusumoto, Nitta, Matsuda, 2014). This is because some people with cerebral palsy have multiple forms of the condition, such as spastic, ataxic, dystonic, or choreo-athetotic cerebral palsy, so identifying the characteristics of a specific form is difficult (Naka, 2009). Moreover, only certain of those people can maintain a standing position unassisted or safely perform tasks when measuring body sway. Developed by Palisano et al. (1997), the Gross Motor Function Classification System (GMFCS) categorizes the severity of cerebral palsy in terms of gross motor function. However, it seeks to examine control of a standing posture in people with relatively mild cerebral palsy, i.e. level Ⅰ (able to walk without restrictions) or level Ⅱ (able to walk without assistance). Moreover, people with cerebral palsy have difficulty making postural adjustments because they retain primitive patterns of movement and have abnormal muscle tone and neurological damage (Mattiello and Woollacott, 1998). Accordingly, identifying mechanisms of standing postural control in those people is difficult.

The current state of research has been described. Nonetheless, several highly interesting findings regarding standing postural control in people with cerebral palsy have been reported, albeit rarely. Ferdjallah, Harris, Smith, and Wertsch (2002) conducted an experiment involving healthy infants and infants with cerebral palsy that compared body sway in a quiet standing posture with the eyes opened and closed. Results indicated the importance of a synergy of extension and contraction of the limbs, rotation of the body, inversion and eversion of the ankle, and plantar and dorsal flexion during postural stabilization in both groups. In infants with cerebral palsy, extension and contraction of the limbs and rotation of the body are crucial to maintaining balance control. In light of the fact that people with cerebral palsy had greater body sway while standing than healthy people did (e.g. Bahramizadeh et al., 2012), Kusumoto, Nitta, and Matsuda (2014) examined body sway in people of various ages with cerebral palsy to determine the possible effects of an equinus deformity. Results revealed that people with an equinus deformity had less body sway than those without that deformity. Based on this finding, previous studies had failed to account for an equinus deformity, suggesting that the results for people with equinus and people without equinus may have been averaged. Taken together, findings from a series of studies presumably indicate that various parameters are associated with standing postural control in people with cerebral palsy. When coordinated movements of the limbs and ankles occur as a result of an imbalance in muscle activity, posture must be maintained depending on certain parameters. In order to assess instability upon standing in people with cerebral palsy, Tsukimura and Ikeda (1982) cited the need to quantitatively assess whether or not a subject was occupying a sufficient area to remain standing. Results revealed that healthy people and people with cerebral palsy use different strategies to control their posture even if they assumed the same standing position. Such findings are probably important. Hoshikawa (2000) provided instruction in "steadying one's self" (a provider of assistance provided physical assistance and the individual assumed a posture in response to gravity) to help an infant with cerebral palsy assume numerous types of postures in response to gravity (including a standing position). As a result, body sway decreased over the course of instruction and the subject was able to use a greater area to steady herself. In addition to assessing a standing position as a static posture, Hoshikawa (2006) discussed the significance of identifying the manner in which one dynamically deals with the environment in response to gravity.

Over the past few years, a systems approach (e.g. Thelen and Smith, 1998) has been adopted in research on human development. An increasing number of researchers are examining postural motor development from the perspective of an interaction of external information and internal imagery (e.g. Adolph et al., 2012). Instead of the traditional concept of "development," that research often seeks to ascertain the process of "organization." The context for this is that postural motor development does not necessarily proceed in accordance with milestones. Instead, it manifests (and sometimes fails to manifest) through interaction with the environment. Individual differences in development are not aberrations but should instead be viewed as a process of organization (Thelen, Corbetta, Spencer, 1996). If one were to compare the postural motor development of people with typical development and people with cerebral palsy, there are often "differences" in the timing and form of that development in both types of people. However, aspects of "an impairment compared to a healthy state" and "a healthy state compared to an impairment" need to both be determined in order to understand the two forms of development together. A systems approach may be an extremely effective way to achieve that goal. In the area of physical therapy, "patients actively learn about their bodies and they perceive their environment through exploration; physical therapy guides and assists them to find ways to move in accordance with the environment" (Tomita, Takenaka, Tamagaki, 2018). The advocating of clinical techniques for physical therapy will affect trends in future research.

In research to ascertain standing postural control in people with cerebral palsy, one tack is to help with treatment by identifying differences from healthy people during assumption of a conventional "static" posture. In addition, further research is probably needed to understand the standing posture of people with cerebral palsy as a method of "dynamically" dealing with the environment and to use that understanding to aid those people.

## 4. Prospects for research on standing postural control

Most of the studies on standing postural control described thus far have measured body sway as an index of function and balance, i.e. a physical parameter primarily for the musculoskeletal system. Over the past few years, studies have examined elements to improve the stability of a standing position. At the top of the list is light touch contact (LTC).

LTC originated with studies reporting that "postural sway was improved by fingertip contact of less than 100 g (1 N) in a static standing position" (e.g. Holden, Ventura, Lackner, 1994; Jeka and Lackner, 1994). This topic has been researched around the world. In the past, surveying one's surroundings, i.e. a shift in gaze accompanying head movement, was known to decrease the stability of a standing posture. This means that visual input plays an important role in postural control (Shiota et al., 2009). LTC uses sensorimotor information with regard to changes in a standing posture gleaned from contact between the forefinger and a static bar. Balance can be stabilized without using visual input. In an experiment, Holden et al. (1994) found that a force of contact of less than 1 N produced stabilization equivalent to that produced with visual input. Basic studies using LTC clinically have revealed that LTC reduces postural sway in the elderly (Tremblay et al., 2004), and grasping a balloon helps infants learn to walk (Shimatani, Shima, Goto, et al., 2013). Over the past few years, virtual LTC for attachment to the fingertip has been developed (Sakata, Shima, Shimatani, 2016) to reduce the risk of falls by the elderly. Applied research involving healthy people is proceeding. In addition, LTC has been used to help people with hemiplegia after a stroke or people with a condition such as Parkinson's disease to stand, and studies have reported that it reduced body sway while standing (e.g. Cunha, Alouche, Araujo, Freitas, 2012; Franzen, Paquette, Gurfinkel, Horak, 2012).

An important keyword for future research will probably be "active." In an experiment with LTC involving health adults, Watanabe and Tani (2020) used active fingertip contact (adjusted by the subject) and passive contact (the experimenter facilitated contact) to examine body sway in a standing posture. Results revealed that LTC was more effective with active contact. This finding is highly interesting for 2 reasons.

First, research on standing postural control in humans as was surveyed in this paper has primarily assessed a standing position as a static posture, regardless of the differences in experimental conditions. In accordance with an experimenter's instructions, a subject is "required" to maintain a standing posture. We live in a gravitational environment, so we assume a standing posture by making adjustments "ourselves." In other words, the activity of the individual presumably needs to be dealt with in order to ascertain standing posture and its control. Findings from Watanabe and Tani (2020) may provide a new perspective from which to examine a standing posture in humans.

Second, LTC is anticipated to greatly help people with disabilities, and people with cerebral palsy in particular, to assume a standing posture. At the current point in time, findings with regard to LTC in people with cerebral palsy are still being fleshed out. In fact, research is difficult since people with cerebral palsy have varied forms of the condition and some of those people may have damaged somatic sensory nerves or deep sensory nerves. However, a hand is routinely used to support the trunk or back of people with cerebral palsy in care settings for children with disabilities, in instruction in special needs schools, and in clinical rehabilitation. Watanabe and Tani (2020) cited the need to conduct both basic and clinical research on the extent to which a provider of support should touch a person with cerebral palsy and how effective "self-contact" by a person with cerebral palsy would be.

## 5. Future research on standing postural control in people with cerebral palsy

This paper has surveyed trends in research on control of a standing posture by healthy people and people with cerebral palsy, and it has looked into standing postural control primarily through LTC. As indicated by the title, this paper will close by describing the future of research on standing postural control in people with cerebral palsy. As mentioned earlier, Nomura (2011) noted that "few studies have delved into the mechanisms of disability." This point and future developments in research will now be discussed.

Sato (2015) reconsidered the perspective that people with cerebral palsy develop the ability to perform actions despite "a damaged system." Sato contended that the loss of a landing site (the action of specifying a location) was a factor hampering the performance of actions by people with cerebral palsy. "The body provides the basis for a sense of 'here.' The sense of 'here' originates at the same time as an anticipation of how one will move in the world. This allows movement of different parts of the body to a landing site. The individual senses the position of those parts and the potential to move them" (Kawamoto, 2014). When the lower back or legs make contact with the ground, the individual begins to sense the positioning of his body in the environment (Sato, 2015). Due to damage to the maneuvering system originating in the central nervous system, people with cerebral palsy not only have difficulty maneuvering their body but they also have a fundamental hurdle to their development of a self and interaction with the outside world (Sato, 2015). In addition, the "stiff body" of people with cerebral palsy places tension on different parts of the body. As Ayaya and Kumagaya (2010) noted, learning to maintain a posture through extreme effort is closely associated with the nature of the condition.

As mentioned earlier, people with cerebral palsy must assume a "static" standing position, suggesting that they must make unsteady and irregular movements. In addition, "anxiety" or "fear" can manifest as a psychological state with an increase in body sway. A rigid body presumably reduces body sway as well.

The standing posture of people with cerebral palsy needs to be re-assessed; to that end, the strategies they adopt in an effort to adapt to a gravitational environment need to be ascertained. In other words, the process by which people with cerebral palsy master standing postural control needs to be painstakingly identified. Hoshikawa (2006) noted that people with cerebral palsy "have postural disorganization when interacting with the environment." As a new angle for research, experiments need to be promptly designed to dynamically identify the standing posture of people with cerebral palsy. As an example, LTC could be actively used to examine body sway in people with cerebral palsy. The process of readopting and mastering a standing posture by an individual or in accordance with a form of palsy can probably be determined. Plans are to conduct research combining basic and clinical research on control of a standing posture in the future.

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