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Comparative gait analysis between children with autism and age-matched controls: analysis with temporal-spatial and foot pressure variables

Bee-Oh Lim, PhD[1)], David O'Sullivan, PhD[2)*], Bum-Gwon Choi, PhD[3)], Mi-Young Kim, PhD[4)]

[1)] *College of Education, Department of Physical Education, Chung-Ang University, Republic of Korea*
[2)] *Division of Sports Science, Pusan National University: 2 Busandaehak-ro, 63 beon-gil, Geumjeong-gu, Busan 46241, Republic of Korea*
[3)] *College of Education, Department of Physical Education, Chung-Ang University, Republic of Korea*
[4)] *College of Human Ecology, Department of Exercise Rehabilitation Welfare, Sungshin Women's University, Republic of Korea*

Abstract. [Purpose] The purpose of this study was to investigate the gait pattern of children with autism by using a gait analysis system. [Subjects] Thirty children were selected for this study: 15 with autism (age, 11.2 ± 2.8 years; weight, 48.1 ± 14.1 kg; height, 1.51 ± 0.11 m) and 15 healthy age-matched controls (age, 11.0 ± 2.9 years; weight, 43.6 ± 10 kg; height, 1.51 ± 0.011 m). [Methods] All participants walked three times on the GAITRite® system while their plantar pressure was being recorded. [Results] The results showed a reduction in cadence, gait velocity, and step length, and an increase in step width in children with autism. Plantar pressure variables highlight the differences between the active pressure areas, especially in the hindfoot of children with autism. [Conclusion] The results suggest that children with autism have an abnormal gait compared with that of age-matched controls, and thus they need extra attention to correct these abnormal gait patterns.

Key words: Gait analysis, Autism, GAITrite system

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INTRODUCTION

Autism has been defined as a developmental disorder that appears in the first 3 years of life, and can affect the brain's normal development of social and communication skills[1)]. The exact causes of autism are unknown; however, it is believed that it results from a combination of both genetic and environmental factors[2)]. Autism affects boys three to four times more than it affects girls[3)]. In the United States, as many as 1 in 110 children between 3 and 17 years of age have been reported to have autism[4)]. Its broad symptoms can be classified into three major categories affecting the development of communication, social interaction, and cognitive functioning[1)]. Other symptoms include attention difficulties, cognitive deficits, unusual responses to sensory stimuli, anxiety, and problems with motor control[5, 6)].

Previous studies demonstrated various locomotor skills and gait problems associated autism due to a lack of postural control, stability, and balance, as well as due to coordination impairments[7–11)]. Calhoun and associates[2)] reported that hypotonia, muscle rigidity, akinesia, bradykinesia, and postural control impairments can lead to unstable and abnormal movements during daily activities. These abnormal walking patterns can in turn lead to pain, fatigue, and extra joint stresses that can affect a child's functional capabilities and cause an overall reduction in the quality of life[2)]. To develop an effective exercise treatment specific to children with autism, it is vital to be able to accurately evaluate individual autistic gait. Accurate gait analysis is of paramount importance as it leads to a comprehensive understanding of gait characteristics and problems. Furthermore,

*Corresponding author. David O'Sullivan (E-mail: tkdnutter@yahoo.com)

this understanding and the gait data can provide a basis for the development of individualized exercise treatment programs.

Autism affects gait patterns; however, only few studies have used quantitative methods in their analysis[2, 6, 11–13]. Vilensky et al.[12] reported that children with autism have a shorter stride length. On the contrary, Rinehart et al.[13, 14] and Calhoun et al.[2] reported no significant differences in stride length. Furthermore, Vernazza-Martin et al.[6] reported a shorter step length for the autistic group. With the inconsistent data provided by these studies, the behavioral characteristics of children with autism have not been considered, especially when using motion analysis in a laboratory setting.

Some of the current literature reports provided contradictory results, which might be related to the difficulty of collecting data from participants with autism, especially when they were required to perform in an unfamiliar testing environment such as a laboratory[13–16]. If participants have to change their clothes and reflective markers need to be attached to them, as required by some motion capture systems, the participants' maladjustment and anxiety can lead to problematic behavior[17–23]. To overcome these problems, a portable gait analysis system can be advantageous as it can be transported to locations that are considered "familiar environment" by the participants. The gait analysis system requires no reflective markers and tight clothing as do other passive and active motion capture systems. Furthermore, an additional benefit while using the gait analysis system is the provision of details about foot pressure distribution and active foot contact area, which provides information on foot contact mechanics. The purpose of this study was to investigate the gait of children with autism by using temporal-spatial and foot pressure variables.

SUBJECTS AND METHODS

A total of 30 participants were recruited for this experiment. The control group consisted of 15 typically developing age-matched children, 2 girls and 13 boys (mean [M], 11.1 years; standard deviation [SD], 2.9 years). The autistic group consisted of 15 children (M, 11.2 years; SD, 2.8 years), 2 girls and 13 boys. The demographic data of the participants are provided in Table 1. To reduce the variability in the autistic participants' gait, we excluded participants with a diagnosis of Asperger's syndrome, a pervasive developmental disorder not otherwise specified, and/or Rett disorder.

The autistic group was selected from a group of children participating in an adapted physical activity program held at a local community center. Participants were selected according to the *Diagnostic and Statistical Manual*[3], and assessed by a qualified developmental pediatrician or a licensed psychologist. The diagnosis was based on observation of the child and an in-depth interview with the parents/guardian and the child. The inclusion criteria for this study were as follows: (a) a diagnosis of autism, (b) age from 8 to 12 years, (c) ability to follow instructions, and (d) receiving regular adapted physical activity. Any children with autism who had the following conditions were excluded: (a) toe walking (either in the past or at present), (b) severe self-injurious behavior, (c) congenital hip dislocation, (d) severe sensory impairments, and (e) an orthopedic impairment.

Before the participant recruitment, the research ethics board of the investigators' university approved the study protocol. In accordance with institutional review board regulations, parental consent was obtained before collecting data from the children.

The GAITRite® system (CIR Systems Inc., Peekskill, NY, USA), a plantar pressure mat system, was used to collect data. The total length of the walkway was 4.88 m, with pressure sensors covering an active area of 3.66 m length and 0.61 m width. The active area had a total array of 18,432 sensors in a grid (48 × 383), each with a width of 1.27 cm. The sensors provided information about the two-dimensional geometry of the footprints, as well as dynamic pressure mapping during walking by recording the location of the activated sensors and the time of sensor activation/deactivation[14]. For installation, all that is required to set up the system is a flat floor. The reliability and validity of the GAITRite system have been tested and reported to be very high by McDonough et al.[15], for both temporal-spatial variables and pressure distribution.

The GAITRite system was installed in the local gymnasium where the children with autism practiced their exercise daily. The foot dimensions—foot length, foot width, shoe length, shoe width, and leg length—were measured with Martin's joint measurement tool (Martin Co., Japan) by a qualified adapted physical educator. The leg length was defined as the distance from the greater trochanter to the lateral malleolus. After a few minutes of familiarization, involving walking along the walkway, the adapted physical educator judged when the participants were ready. The participants started barefoot walking up to 8 m before they stepped onto the GAITRite pressure mat and finished at a distance of 8 m beyond the mat. In each trial, the participants were encouraged by the coach to maintain their most natural gait pattern and speed. The average of three trials for the dominant (right) foot was calculated for analysis.

The temporal-spatial and pressure distribution variables were calculated by using the GAITRite software. Figure 1 illustrates the temporal definitions for the right and left legs when they are in contact with the active sensor area. The step time (s) was defined as the time elapsed from the first foot contact to the first contact of the opposite foot. The gait cycle time was defined as time elapsed from the first contacts of two consecutive footprints of the same foot. The single leg support time (s) was defined as the time the opposite foot is swinging to the next step, and the double support time (s) was defined as the time when both feet are in contact with the ground. The stance time (s) was defined as the time between the first and last contacts of the same footprint, and the swing time (s) was defined as the time between the last contact of the current footprint and the first contact of the next footprint of the same foot. The ambulation time (s) was defined as the time from the first footprint heel's center of pressure to the last footprint toe's center of pressure.

Figure 2 shows the spatiotemporal measurements of the GAITRite system. The distance (cm) was defined from the center of pressure of the first heel to the center of pressure of the toe of the last footprint. The gait velocity (m/s) was calculated by dividing the recorded distance by the ambulation time. To calculate the normalized velocity ($m \cdot s^{-1} \cdot cm^{-1}$), the walking velocity (m/s) was divided by the average leg length (cm). The lower-limb length was measured from the greater trochanter to the floor for both legs. The stride velocity (m/s) was calculated by dividing the stride length by the stride time. The step length (cm) was calculated from the distance of the center of pressure of the heel of the current footprint to the same distance of the previous footprint on the opposite foot. The stride length (cm) was calculated from the line of progression between the heel points of two consecutive footprints of the same foot (A–G). The step width (cm) was calculated as the distance between the progression line of one foot to the opposite foot (D–L). The toe-out angle (°) was calculated as the angle of the foot relative to the progression line (+a). The step/extremity ratio was calculated by dividing the step length by the leg length.

Figure 2 shows the footprint details demonstrating the pressure distribution and the associated variables. According to the GAITRite system, the footprint was divided into 12 trapezoids, 6 for the lateral part (1–6) and 6 for the medial part (7–12). Each trapezoid, nonsquare, included a specific number of sensors, and the order for assigning sensor activation was from heel to toe. The trapezoids were classified into three segments: hindfoot (trapezoids 1, 2, 7, and 8), midfoot (trapezoids 3, 4, 9, and 10), and forefoot (trapezoids 5, 6, 11, and 12). The segmental integrated pressure over time (P*t) was defined as the percent of the overall integrated pressure over time. The peak time (s) was defined as the first time point of each trapezoid when one or more sensors within a segment are at the maximum. The active area was defined as a percentage of the sum of the active sensors within one segment. The peak pressure was defined as the maximum level expressed as a percentage of the overall maximum switching level at the peak time in a segment.

All dependent temporal-spatial and pressure distribution variables were entered into the SPSS software (version 18.0; SPSS Inc., Chicago, IL, USA). To investigate the differences between the means of the two groups, independent t-tests with Bonferroni adjustments were performed with a significance level of 0.05. Significant differences between groups were further evaluated by using Cohen's effect sizes[21].

Table 1. Participant characteristics for the autism group and age-matched control group

Variables	Autism	Control
No. of subjects	15	15
Age (years)	11.2 (2.80)	11.01 (2.89)
Height (cm)	150.9 (11.26)	151.3 (11.93)
Weight (kg)	48.1 (14.12)	43.6 (10.01)
Shoe size (cm)	243.7 (18.07)	244.0 (17.74)
Leg length (cm)	76.8 (9.89)	77.5 (7.86)

Data are presented as mean (SD)

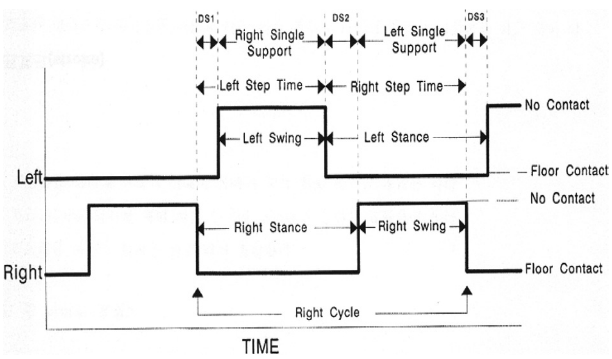

Fig. 1. Temporal definitions (GAITRite operation manual, 2001)

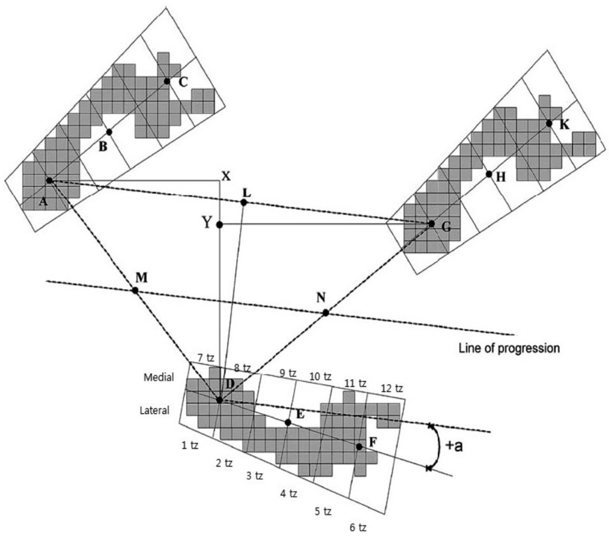

Fig. 2. The spatiotemporal measurements of the GAITRite system are based on three footprints

The gray squares represent the pressure sensors, and the trapezoids (nonsquares) of each foot are the technical basis for footprint calculations. Points A, D, and G are the geometric centers of the heel for each footprint. Line AG represents the stride length of the left foot, line AX the step length of the right foot, line YG the step length of the second left footprint, and line DL the step width. The line of progression connects midpoint M of line AD with midpoint N of line DG. The toe-in/toe-out angle is between the geometric midline of the right footprint and the line of progression. The angle is zero if the geometric midline of the footprint is parallel to the line of progression; positive when the midline of the footprint is outside the line of progression; and negative if it is inside the line of progression[14].

RESULTS

All temporal and spatial variables are shown in Table 2. The cycle time, p = 0.042 (autism cv [coefficient of variation]= 9.09, control cv = 10.87); double support time, p = 0.004 (autism cv = 18.18, control cv = 22.22); and stance time, p = 0.01 (autism cv = 9.84, control cv = 18.87) were all significantly longer for the group with autism than for the control group. The cadence, p = 0.048 (autism cv = 8.34, control cv = 14.73), for the group with autism was lower than that for the control group. For the normalized velocity, p = 0.009 (autism cv = 12.96, control cv = 24.51), and stride velocity, p = 0.038 (autism cv = 33.91, control cv = 24.51), the experimental group was significantly slower. The step width, p = 0.008 (autism cv = 51.96, control cv = 33.94), was significantly wider for the group with autism than for the control group. The step/extremity ratio, p = 0.017 (autism cv = 12.20, control cv = 10.99), was significantly lower for the group with autism than for the control group.

The footprint pressure variables are presented in Table 3. In the lateral footprint, there were significantly longer times to peak pressure for the group with autism in trapezoid 2, p = 0.002 (autism cv = 33.33, control cv = 60.00); trapezoid 3, p = 0.007 (autism cv = 62.50, control cv = 75.00); trapezoid 4, p < 0.001 (autism cv = 33.33, control cv = 60.00); trapezoid 5, p = 0.001 (autism cv = 30.00, control cv = 50.00); and trapezoid 6, p = 0.009 (autism cv = 42.86, control cv = 40.00).

In the medial footprint, there were significantly longer times to peak pressure for the group with autism in trapezoid 8, p = 0.009 (autism cv = 57.14, control cv = 100.00); trapezoid 10, p = 0.006 (autism cv = 100.00, control cv = 25.00); trapezoid 11, p = 0.007 (autism cv = 33.33, control cv = 33.33); and trapezoid 12, p = 0.008 (autism cv = 37.50, control cv = 40.00). This meant that the peak pressure times were later in the group with autism than in the control group.

There was a significant difference at the hindfoot between the group with autism and the control group for the distribution of the integrated pressure over time, p = 0.023 (autism cv = 35.06, control cv = 39.22) (Table 4). As for the active area in the hindfoot, there was a significantly smaller area for the group with autism than for the control group, p = 0.039 (autism cv = 14.39, control cv = 6.80) (Table 4). There was also a significantly smaller value at the hindfoot for the group with autism than for the control group for the peak pressure, p = 0.041 (autism cv = 35.34, control cv = 38.86) (Table 4).

DISCUSSION

The purpose of this study was to investigate the gait patterns of children with autism by using temporal-spatial and foot pressure variables. Among the temporal variables, cycle time, double support time, and stance time were significantly longer for the autistic group. Among the spatial variables, cadence was significantly lower for the autistic group than for the control group. For the normalized velocity and stride velocity, the autistic group was significantly slower than the control group. For the step width, the autistic group showed significantly wider values than the control group. For the step/extremity ratio, the autistic group had significantly lower values than the control group.

Vernazza-Martin et al.[6] compared the step length of nine young autistic boys (age, 4–6 years) with an age-matched control

Table 2. Temporal and spatial gait variables

Variables	Autism	Control
Step time (s)	0.49 (0.04)	0.46 (0.05)
Cycle time (s)	0.99 (0.09)	0.92 (0.10)*
Single support time (s)	0.39 (0.04)	0.39 (0.02)
Double support time (s)	0.22 (0.04)	0.18 (0.04)*
Swing time (s)	0.38 (0.04)	0.39 (0.03)
Stance time (s)	0.61 (0.06)	0.53 (0.10)*
Ambulation time (s)	2.47 (0.72)	2.14 (0.47)
Distance (cm)	291.54 (34.34)	292.62 (23.73)
Cadence (steps/min)	120.79 (10.07)	132.72 (19.55)*
Velocity (m/s)	1.25 (0.23)	1.43 (0.30)
Normalized velocity (m/s/cm)	1.62 (0.21)	2.04 (0.50)*
Stride velocity (m/s)	1.15 (0.39)	1.43 (0.30)*
Step length (cm)	62.64 (10.48)	64.01 (8.79)
Stride length (cm)	124.45 (22.96)	128.91 (17.94)
Step width (cm)	11.99 (6.23)	7.10 (2.41)*
Toe-out angle (°)	8.19 (11.39)	2.46 (5.16)
Step length/extremity ratio (cm/leg length)	0.82 (0.10)	0.91 (0.10)*

Data are presented as mean (SD).
*Significant differences between groups, p < 0.05

group consisting of six boys (age, 4–6 years). They showed that the autistic boys had a shorter step length. Vilensky et al.[12] reported similar results for a control group of 15 boys (age, 3.3–10 years; mean, 6.1 years) and an autistic group of 21 boys (age, 3.9–11.3 years; mean, 7.1 years). Contrarily, Rinehart et al.[13] found increased step length variability but no reduction in step length between 10 boys with autism and 10 aged-matched control boys (age, 6.8–14.4 years). In this study, there was no significant difference in step length between the control and autistic groups. However, when the step length was normalized by the leg length, the autistic group had shorter step than that of the control group (Table 2). One of the reasons for the discrepancies between each of the studies[13] was the differences in the matching of controls; that is, leg length was used in this study, whereas Rinehart et al.[13] used age, gender, and intelligent quotient.

Vilensky et al.[9] reported results similar to ours, as the stance time was statistically longer for the autistic group than for the control group. However, Calhoun et al.[2] reported opposite results to those of our study, as they reported that cadence was higher for the autistic group than for the control group aged between 5 and 9 years (mean age, 6.3 years; mean height, 121.0 cm; mean weight, 29.3 kg). In the study by Calhoun et al.[2], there was no statistical difference between the gait velocities. In our study, cadence, stride velocity, and normalized velocity were lower for the autistic group than for the control group. A suspected reason for the differences may be the age of the participants, as the participants in the study by Calhoun et al.[2] averaged 6.3 years (5–9 years) in age, whereas the participants in our study averaged 11.2 years (8–12 years) in age. With the uncertainty of the effect of age, it may be useful to investigate age as a confounding factor in autistic gait.

The gait cycle time and double support time have not been previously reported for autistic children. In this study, both gait cycle time and double support time were significantly longer for the autistic group than for the control group. Also for the step width, the autistic group showed significantly wider step than did the control group. It has been observed that the gait of the elderly is similar to that of autistic children, as their step width is wider and the cycle time, double support time, and

Table 3. Peak time (s) of pressure sensor activation in footprint partitioned into 12 trapezoids of gait

Variables		Autism	Control
Lateral footprint	Trapezoid 1	0.17 (0.15)	0.18 (0.18)
	Trapezoid 2	0.09 (0.03)	0.05 (0.03)*
	Trapezoid 3	0.08 (0.05)	0.04 (0.03)*
	Trapezoid 4	0.09 (0.03)	0.05 (0.03)*
	Trapezoid 5	0.10 (0.03)	0.06 (0.03)*
	Trapezoid 6	0.07 (0.03)	0.05 (0.02)*
Medial footprint	Trapezoid 7	0.47 (0.15)	0.49 (0.11)
	Trapezoid 8	0.07 (0.04)	0.04 (0.04)*
	Trapezoid 9	0.01 (0.04)	0.01 (0.01)
	Trapezoid 10	0.04 (0.04)	0.01 (0.01)*
	Trapezoid 11	0.09 (0.03)	0.06 (0.02)*
	Trapezoid 12	0.08 (0.03)	0.05 (0.02)*

Data are presented as mean (SD).
*Significant differences between groups, $p < 0.05$

Table 4. The distribution of integrated pressure over time (P*t); the active area; and the peak pressure between the hindfoot, midfoot, and forefoot

Variables		Autism	Control
P*t (%)	Hindfoot	23.39 (8.20)	32.87 (12.89)*
	Midfoot	24.68 (8.40)	21.54 (6.20)
	Forefoot	52.07 (10.57)	45.67 (12.74)
Active area (cm^2)	Hindfoot	38.51 (5.54)	42.05 (2.86)*
	Midfoot	26.78 (5.84)	24.81 (3.87)
	Forefoot	34.21 (4.76)	33.32 (2.83)
Peak pressure (%)	Hindfoot	20.91 (7.39)	28.23 (10.97)*
	Midfoot	25.53 (7.96)	24.58 (8.03)
	Forefoot	53.69 (8.27)	47.30 (11.83)

Data are presented as mean (SD).
*Significant differences between groups, $p < 0.05$.

stance time are longer[19]. It is reported that the gait of autistic children and that of the elderly seem similar because of the lack of control, and thus a general characteristic of increasing the step width for greater stability is observed in these groups[19].

There is a void of data about the role of plantar pressure distribution in young children with autism. In this study, plantar pressure was divided into 12 trapezoids, with each trapezoid evaluated for pressure according to time, maximum pressure, time to maximum pressure, and area of pressure distribution. The segmental integrated pressure over time in the hindfoot was statistically lower for the autistic group than for the control group. Also, the active area of pressure in the hindfoot was significantly lower for the autistic group than for the control group. Finally, the peak pressure had a lower percentage in the autistic group than in the control group. This is due to the characteristics of flat foot that are associated with autism. In this study, while there was a reduction in the velocity in the autistic group, there was also a reduction in the pressure distribution in the hindfoot. Consistent with our study, other studies illustrate that the pressure distribution is affected by gait velocity: when the velocity is reduced, the pressure in the hindfoot is also reduced[12]. Similarly, Zhu et al.[24] indirectly highlighted the cause and effect of gait velocity by reporting the positive relation between cadence and peak plantar pressure. Titianova et al.[19] reported that the time to maximum pressure occurred later for heavier participants, and that the active area was wider in the midfoot, whereas the maximum pressure was higher in the hindfoot. In this study, the control group participants were heavier, the time to maximum plantar pressure was longer, and the active area was wider for the midfoot; however, the opposite tendencies were observed in the hindfoot.

In this study, a novel gait analysis system was used instead of the standard three-dimensional motion analysis system. Some of the main advantages of the gait analysis system are its ease of use in any gymnasium, the lack of preparation required, and the convenience of not having the need for a change of clothes and the preparation of markers (either active or passive), which usually exist when using other motion analysis systems. These advantages are especially important when the participants are autistic children, because many of these children may refuse to participate in the experiment when they are introduced into an unfamiliar environment. The gait analysis system also provides footprint analysis, which may help reveal underlying foot and gait problems that are critical for the development of rehabilitation strategies. A clinician may be able to develop a treatment, based on the gait analysis, that can increase the ability of autistic children in terms of locomotor skills[15], thus helping with their motor development. Notably, one limitation of this novel gait analysis system is that it cannot be used to investigate the relation between lower-limb kinematics and plantar pressure.

In conclusion, the main findings of this study demonstrate a gait in autistic children that is characteristically similar to the elderly gait, i.e., a reduction in cadence, gait velocity, and step length, and an increase in step width. The plantar pressure reveals the lack of control of the plantar flexion and highlights the flat foot of autistic children. Future studies may focus on other factors, such as cognitive functioning, age, and fitness level, that affect gait in autistic children.

REFERENCES

1) American Psychiatric Association: DSM-5 developmental. http://dsm5.org/Pages/Defaults.aspx (Accessed Apr. 14, 2014)
2) Calhoun M, Longworth M, Chester VL: Gait patterns in children with autism. Clin Biomech (Bristol, Avon), 2011, 26: 200–206. [Medline] [CrossRef]
3) American Psychiatric Association: Diagnostic and statistical manual of mental disorders. Washington DC, 2000.
4) Kogan MD, Blumberg SJ, Schieve LA, et al.: Prevalence of parent-reported diagnosis of autism spectrum disorder among children in the US, 2007. Pediatrics, 2009, 124: 1395–1403. [Medline] [CrossRef]
5) Hallett M, Lebiedowska MK, Thomas SL, et al.: Locomotion of autistic adults. Arch Neurol, 1993, 50: 1304–1308. [Medline] [CrossRef]
6) Vernazza-Martin S, Martin N, Vernazza A, et al.: Goal directed locomotion and balance control in autistic children. J Autism Dev Disord, 2005, 35: 91–102. [Medline] [CrossRef]
7) Shumway-Cook A, Woollacott MH: Dynamics of postural control in the child with Down syndrome. Phys Ther, 1985, 65: 1315–1322. [Medline]
8) Minshew NJ, Sung K, Jones BL, et al.: Underdevelopment of the postural control system in autism. Neurology, 2004, 63: 2056–2061. [Medline] [CrossRef]
9) Chen Y, Chen C, Wang C, et al.: Comparison of dynamic balance under dual and simple task conditions in children with attention deficit hyperactivity disorder. J Phys Ther Sci, 2012, 24: 633–637. [CrossRef]
10) Shimatani K, Sekiya H, Tanaka Y, et al.: Postural control of children with developmental disorders. J Phys Ther Sci, 2009, 21: 7–11. [CrossRef]
11) Al-Heizan MO, AlAbdulwahab SS, Kachanathu SJ, et al.: Sensory processing dysfunction among Saudi children with and without autism. J Phys Ther Sci, 2015, 27: 1313–1316. [Medline] [CrossRef]

12) Vilensky JA, Damasio AR, Maurer RG: Gait disturbances in patients with autistic behavior: a preliminary study. Arch Neurol, 1981, 38: 646–649. [Medline] [CrossRef]
13) Rinehart NJ, Tonge BJ, Bradshaw JL, et al.: Gait function in high-functioning autism and Asperger's disorder: evidence for basal-ganglia and cerebellar involvement? Eur Child Adolesc Psychiatry, 2006, 15: 256–264. [Medline] [CrossRef]
14) Rinehart NJ, Tonge BJ, Iansek R, et al.: Gait function in newly diagnosed children with autism: cerebellar and basal ganglia related motor disorder. Dev Med Child Neurol, 2006, 48: 819–824. [Medline] [CrossRef]
15) Choi BK, Kim MY, Lim BO: Analysis of gait characteristics using GAITRite® system in children with down syndrome. Kor J Ad Phys Act, 2011, 19: 123–134.
16) Bandini LG, Gleason J, Curtin C, et al.: Comparison of physical activity between children with autism spectrum disorders and typically developing children. Autism, 2013, 17: 44–54. [Medline] [CrossRef]
17) Uesugi M, Miyamoto A, Nanba Y, et al.: Relationships between problematic behaviors and motor abilities of children with cerebral palsy. J Phys Ther Sci, 2015, 27: 2963–2964. [Medline] [CrossRef]
18) Kim MY, Choi BK, Lim BO: Analysis of obstacle gait using spatio-temporal and foot pressure variables in children with autism. Kor J Sp Biomech, 2001, 21: 459–466. [CrossRef]
19) Titianova EB, Mateev PS, Tarkka IM: Footprint analysis of gait using a pressure sensor system. J Electromyogr Kinesiol, 2004, 14: 275–281. [Medline] [CrossRef]
20) McDonough AL, Batavia M, Chen FC, et al.: The validity and reliability of the GAITRite system's measurements: a preliminary evaluation. Arch Phys Med Rehabil, 2001, 82: 419–425. [Medline] [CrossRef]
21) Cohen J: Statistical power analysis for the behavioral sciences, 2nd ed. 1988.
22) Kirtley C: Clinical Gait Analysis: Theory and Practice. London: Churchill Livingstone, 2005.
23) Andriacchi TP, Ogle JA, Galante JO: Walking speed as a basis for normal and abnormal gait measurements. J Biomech, 1977, 10: 261–268. [Medline] [CrossRef]
24) Zhu H, Wertsch JJ, Harris GF, et al.: Walking cadence effect on plantar pressures. Arch Phys Med Rehabil, 1995, 76: 1000–1005. [Medline] [CrossRef]