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Marco TRAMONTANO, Giovanni MORONE, Andrea CURCIO, Giulia TEMPERONI, Alessandra MEDICI, Daniela MORELLI, Carlo CALTAGIRONE, Stefano PAOLUCCI, Marco IOSA

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Managing the mantainment of gait stability during dual walking task: effects of age and neurological disorders.

Tramontano Marco[1], *Morone Giovanni*[1], *Curcio Andrea*[1], *Temperoni Giulia*[1], *Medici Alessandra*[1], *Morelli Daniela*[1], *Caltagirone Carlo*[1,2], *Paolucci Stefano*[1], *Iosa Marco*[1].

[1] I.R.C.C.S Santa Lucia Foundation, Rome, Italy

[2]Department of System Medicine, "Tor Vergata" Rome, Italy

Corresponding author: Giovanni Morone, MD
I.R.C.C.S. Fondazione Santa Lucia - Via Ardeatina 306, 00179 Rome, Italy
e-mail: g.morone@hsantalucia.it
Tel 0039 0651501005 Fax 0039 0651501004

ABSTRACT

BACKGROUND: Dual task paradigm is common mechanism of daily life, it is often used for investigating the effect on cognitive processing of motor behavior. AIM: In the present study we investigate the dual task interference during walking on upright gait stability. DESIGN: cross-sectional study. SETTING: Inpatient neurorehabilitation unit and children neurorehabilitation unit POPULATION: Eighty-five subjects were enrolled, divided into five groups: healthy young, healthy elderly, children with typical development, children with cerebral palsy and adults with stroke in subacute phase. METHODS: All subjects had to walk through a pathway during which they had to hear a sound, turn the head to watch a number and verbalize it. Subjects wore an accelerometer on their lumbar spine to measure upright gait stability have been assessed by means of the Root Mean Square (RMS) of the trunk acceleration. RESULTS: All subjects showed a reduced speed when performing a dual task with respect to single task. This reduction was significantly different among groups (F(4,81)=12.253, p<0.001, ES=0.377). The RMS resulted increased along LL-axis, and reduced along AP- and CC-axes during the dual task walking. CONCLUSION: These accelerations were significantly related to the changes in speed that were managed in a different way in subjects affected by cerebral palsy and stroke. CLINICAL REHABILITATION IMPACT: The information obtained in this study may be used to support specific rehabilitation techniques in subjects with poor balance ability.

Key words: Dual Task, Balance, Cerebral Palsy, Elderly, Stroke.

INTRODUCTION

During walking in daily life, it is often required to turn the head for looking something happening in the surrounding environment, for example when we hear a sudden noise, when we have to cross the road, when we would just look something interesting around us, or when we have to verbally respond to our converser without stopping walking.

This common mechanism of daily life has been defined as dual task paradigm that became an experimental procedure often used in neuropsychology for investigating the effect of cognitive processing on motor behavior [1]. In most of the study, the experimenter asks to the subject to perform two tasks simultaneously: if the performance is inferior in quality or longer in time to that observed during a single task, it means that the two tasks interfere with each other, and this implies that they "compete" for the same resources in the cognitive and sensori-motor systems [2].

This dual task can be demanding in elderly and even more in individuals with a brain pathology and those with difficulties in distributing attentional resources to different tasks [3, 4]. Subjects affected by cerebrovascular stroke showed a walking speed decrease, an increase of double support and a balance alteration in a cognitive and motor dual task experiment [3, 5-12]. Not only impairment can affect the management of a dual walking task, aging affects the performance with a decreased balance control and hence an increased risk of fall [3, 4, 13, 14]. The effect of age is not only related to elderly, but also to children: for example it has been shown that pre-scholar children might still be developing their ability to perform activities requiring dual-task constraints that involve simultaneous use of the upper limbs during walking [15].

Despite this last study investigating 3 age-groups of children, most of the study investigates only 1 group of subjects in single vs. dual task, or 2 groups of subjects [16, 17]. So, an overview about walking performance during dual task is possible only comparing results of different studies, as done in a recent review [18].

The aim of this study was to investigate the effect of brain damage and age on dual task interference during walking in five different groups of subjects: a group of healthy young subjects, a group of healthy elderly, a group of children with typical development, a group of children with cerebral palsy and a group of adults with stroke.

METHODS

Participants

Eighty-five subjects were enrolled in this study, divided into 5 groups, 15 children with CP mean age 6.40±2.56 (5 di paresis, 4 right hemiparesis, 4 left hemiparesis, 1 ataxia, 1 tetraparesis) 10 children with typical development mean age 7.00±2.54, 20 healthy young adults mean age 23.80±3.00, 20 healthy elderly mean age 68.60±6.14 and 20 subject with stroke mean age 68.73±7.07, 10 left hemiparesis (7 ischemic and 3 hemorrhagic) and 10 right hemiparesis (7 ischemic and 3 hemorrhagic)

Demographical and clinical features of the 5 samples of enrolled subjects are shown in Table 1.

Inclusion criteria for patients with stroke were: clinical diagnosis of cerebrovascular accident, subacute phase of stroke (less than 6 months from acute event), ability to walk independently (with or without the aid of a cane or tripod), cognitive ability to understand the given instructions during the test (cognitive level was assessed with the "Mini Mental State Examination, and only patients with a score greater than or equal to 24 have been enrolled [19]). Inclusion criteria for children with cerebral palsy were: clinical diagnosis of cerebral palsy, age between 3 and 12 (according to previous studies on walking in children with CP) [20, 21], ability to walk independently, cognitive ability to understand the given instructions during the test (cognitive level was assessed with the intelligence quotient > 49 assessed by a psychologist using the revised version of Wechsler Intelligence Scale for Children). Exclusion criteria were common to the two impaired groups: visual deficit not compensated with glasses, acoustic deficits not compensated with an acoustic device, unilateral spatial neglect (diagnosed with a battery of test including Letter Cancellation test, the Barrage test, the Sentence Reading test and the Wundt-Jastrow Area Illusion Test) and severe aphasia (diagnosed with neuropsychological assessment), severe muscle contractures, bone deformities and serious visual fixation disorders (Southern California College of Optometry System Infants with a score of 1 were excluded because of their changeable fixation).

This study was approved by the Local Independent Ethics Committee (prog.436/14) and all participants or parents for children gave their written informed consent to participate in the study.

Experimental Protocol

In a clinical setting, many different protocols and measures of dual-task performance have been proposed and based on the use of simple available equipment, such as walkways and stopwatches, whereas the second task could be a motor one such as obstacle avoidance or objects to carry or cognitive such as tasks related to reciting the phonetic alphabet, serial subtractions, or simple questions based on auditory and/or visual discrimination [22]. Because of our study enrolled patients and children we have designed our protocol in accordance with this last option of a simple question based on auditory and visual discrimination, and in accordance with their abilities (for example young children were unable to count digits). The study was carried out in an empty wide room of our hospital where only one patient, two examiners were present with a table and a computer on it. The examiners were positioned laterally to the pathway and in correspondence of its half in order to play the sound when the patient reached that point, and to guarantee the same head rotation for all patients

All adult subjects had to walk through a path of 7m wearing an accelerometer [23] placed on a band located at the lumbar level (the height of L2-L3), to detect latero-lateral, anterior-posterior and cranio-caudal accelerations (sampling frequency = 20Hz). Subjects were asked to walk without stop from starting line to stopping line, and it was explained them that, during the task, they might hear a sound, and in that case they should look towards the experimenter who is showing a number from 0 to 5 with his fingers, subject should verbalize this number during their walking. Each subject performed eight trials in order to have at least two measurements with sound stimulus by side (left and right) randomly alternated between paths with and without emission of sound. For children the protocol was the same, but a path of 6m and the recognition of closed or opened hand of experimenter (instead of a number).

Measurements

During the test, a triaxial wireless accelerometer was used to assess upright gait stability as accelerations along its three axes, which were aligned with the anatomical axes of the trunk (anterior-posterior, latero-lateral, cranium-caudal). The accelerometer collected data with a sampling frequency of 100Hz, and had a measuring range of ± 6g (equal to ± 59m/s^2). It was wireless, light (a weight lower than 100g), and small. It was placed through a band at the lumbar level (at the height of L2-L3). According to many previous studies (for a review see [24]), upright gait stability have been assessed by means of the Root Mean Square (RMS) of the three components of acceleration after mean subtraction and low-pass filtered (at 20Hz). The mean subtraction implied that the RMS corresponds to the standard deviation of acceleration signal and it is hence informative of the dispersion of the accelerations. The time spent by subject to complete each trial of the test was also computed analyzing the accelerations for identifying the walking start and stop. Average walking speed was computed as the length of the path divided by the time spent to complete the task.

Elderly subjects and those affected by stroke were assessed by means the Berg Balance Scale that was developed to measure balance function by assessing the performance of functional tasks. This is a five-point scale, ranging from 0-4. “0” indicates the lowest level of function and “4” the highest level of function. Total Score = 56. The BBS interpretation lead to low (<20) medium (21-40) and high (41-56) fall risk [25].

Pediatric populations with typical development and those affected by CP were assessed by Pediatric Balance Scale (PBS). This is a 14-item criterion-referenced measure which examines functional balance in the context of everyday tasks in the pediatric population [26].

Tinetti Gait Balance Scale evaluates balance and gait in elder patients. It is composed of two sections, one dedicated to balance and made up of 9 items, and one dedicated to gait and made up of 7 items. The total score ranges from 0 to 28, is given by the sum of the two sections of the "balance" side, with a maximum score of 16, and the "gait" size, with a maximum score of 12 [27].

The Timed Up and Go Test can examine functional mobility of a patient, and can evaluate the risk of falling in patients older than 65. It measures in seconds the time used by a patient to get up from a seat with armrests, walk on a 3 meters path, turn around, walk back and sit down again [28].

The GMFM-88, Gross Motor Function Measure is the most commonly used scale to gross motor evaluation in children with cerebral palsy. It evaluates gross-motor competence in children affected by cerebral palsy, to measure if they are equal or lower than normal subjects within five years of age [29].

Statistic analysis

The data were reported in terms of means and standard deviations. The computed parameters (time and acceleration) were analyzed by repeated measures analysis of variance (RM-Anova) using the group as a five-variant between-subjects factor and task as a bivariate factor within subjects (task: single task walking vs. dual task walking). The RM-Anova was followed by the post-hoc tests when appropriated. Moreover, possible correlations (Spearman's R) between the recorded parameters and clinical scales scores were assessed. For all tests the level of statistical significance was set at 0.05, except for the post-hoc tests for which the Bonferroni correction was applied (reducing alpha level at 0.025).

RESULTS

Eighty-five subjects were enrolled in this study, divided into 5 groups, 15 children with CP mean age 6.40±2.56 (5 di paresis, 4 right hemiparesis, 4 left hemiparesis, 1 ataxia, 1 tetraparesis) 10 children with typical development mean age 7.00±2.54 , 20 healthy young adults mean age 23.80±3.00, 20 healthy elderly mean age 68.60±6.14 and 20 subject with stroke mean age 68.73±7.07, 10 left hemiparesis (7 ischemic and 3 hemorrhagic) and 10 right hemiparesis (7 ischemic and 3 hemorrhagic). Despite allowed, nobody of subjects performed the test using a cane or a tripod.

Not all subjects, when asked to perform the dual walking task showed a reduced speed with respect to single task (Figure 1). This reduction was significantly different among groups (F(4,81)=12.253, $p<0.001$, ES=0.377). Post-hoc analysis showed significantly differences from healthy adults (showing a speed reduction of -1.2±3.8%) for subjects with stroke (-15.6±8.6%, p=0.005) and children with cerebral palsy (-15.3±11.3%, p=0.011). Also elderly (-8.6±6.0%) and children with typical development (-4.9±7.8%) showed a significant reduction of walking speed with respect to healthy young adults ($p<0.001$ and p=0.018, respectively). Further, the speed change resulted different between healthy elderly and age-matched subjects with stroke (p=0.035) and between children with cerebral palsy and those with typical development (p=0.011).

In general, the acceleration RMS resulted increased along LL-axis, and reduced along AP- and CC-axes during the dual task walking. The differences among the five groups did not result statistically significant. However, many of these differences resulted significantly related to the changes in speed, as shown in Table 2. For this reason Anova was performed using change in speed as covariate variable showing statistically significant differences among groups for the changes in aRMS along LL (F(4,80)=2.825, p=0.030, ES=0.124), CC (F(4,80)=4.559, p=0.002, ES=0.186) and AP (F(4,80)=3.097, p=0.020, ES=0.134).

For patients with stroke, the relationship between BBS-score and changes in a RMS-CC were quadratic (R^2=0.307, p=0.044) and not linear (R^2=0.069, p=0.262), as shown in Figure 2. A quadratic trend was observed also for aRMS-CC in children with CP with respect to PBS-score (quadratic fit R^2=0.318, p=0.100 vs. linear fit R^2=0.056, p=0.396), but it has an opposite concavity and it was not statistically significant.

Discussion

Healthy young adults were able to perform the dual task without varying gait speed and trunk accelerations with respect to single walking task. Surprisingly, the trunk accelerations of adult and children patients were not higher than those of healthy subjects. The differences were found in terms of walking speed, with patient's walking slowed down during dual task more than that of healthy subjects. But when analyses were corrected for speed, the differences in terms of trunk stability emerged as statistically significant among groups. This was probably the most important finding of this study: adult and children patients performed the dual task reducing the walking speed probably for avoiding an increment of trunk acceleration and hence a reduction of stability.

These findings are in line with previous ones reporting that healthy young subjects have no difficulties in maintaining walking speed while performing another task, whereas dual task can be demanding in elderly subjects. For example, it has been shown as gait speed and balance control decrease during walking and talking at the same time [6, 30]. Also our healthy elderly subjects reduced walking speed, and it seemed a good strategy for maintaining accelerations in LL-direction similar to those observed in single walking task. These difficulties may enhance in individuals with a brain pathology, for their impaired balance control [13, 14]. In turn, it may increase the risk of falling also in patients with difficulties in distributing attentional resources to different tasks [3, 4].

Our results showed that also children with typical developing reduced speed during dual-task, similarly to healthy elderly, but children also increased accelerations along LL-direction. This difference seems to be in line with previous results [31] showing that younger children having less developed executive attention and postural control compared with older children and adults, experienced postural control interference when an attentionally demanding cognitive task was performed in static stance. But the effect of dual task on walking of children has been poorly investigated. A recent work showed [32] that children with CP have different postural control during dynamic activities. Indeed a secondary task performed during gait can produce a reduction of speed gait in children with CP [33, 34]. Ya-Ching-Hung showed that children with unilateral CP changed their gait performance and bimanual coordination under dual task condition with a secondary motor task [35].

The original approach of our study was not only to provide an overview of the combined effect of age and pathology on speed, but to investigate also gait stability in terms of trunk acceleration. As above stated, we found that all subjects tried to do not reduce their gait stability, preferring a reduction of speed. Interestingly, subjects with stroke with higher increase in trunk accelerations were those with a poor balance (Berg balance scale score <29: high fall risk), as it could be expected, and also those with a good balance (Berg balance scale score >49: low fall risk), as shown in Figure 2 in which a quadratic trend was highlighted. This result was unexpected. Those who did not increase their trunk accelerations were those with a medium level of balance (Berg balance scale score between 29 and 49). Morone and colleagues [36] reported that patients who are more prone to perceive as comfortable a high speed, are those more exposed to a higher risk of falling. Similar results were observed by Simpsons et al; that observed that a faster Timed Up and Go Test was associated with greater falls for the stroke [37]. Authors hypothesized that these patients recovered a lot of their functions, but not completely, resulting in being not completely aware of their new reduced locomotor abilities and hence being those who did not take into account that a higher walking speed implies higher trunk accelerations to manage. This trend was not observed in children with cerebral palsy, probably because they developed their gait with altered functions [38] and did not loss acquired pattern [39]. Their capacity of imagining their locomotor actions has been shown to be altered, bringing them to overestimation of their abilities [40], but in our study we found a difference with respect to patients with stroke for whom this overestimation occurred in subjects with good balance. Finally, differently from healthy elderly, children with typical development accepted to managing higher trunk accelerations during dual-task walking.

One limitation to consider is definitely the setting in which the study was held, that does not faithfully reproduce a journey during activities of daily life: the patients were in a safe environment, constantly accompanied by a therapist during the wanderings. Although the study was randomized, so the subjects did not know when they were going to hear the sound, this always came from the same source (computer). Another limitation of our study was the choice of a very simple question (visual discrimination of number of digits for adults or of open-closed hand for children) during the dual-task: it implied that few sporadic errors occurred without any possibility of statistical analysis on the correlation between cognitive and motor tasks. Further studies, using a different test, may also assess cognitive performance and evaluated its correlation with motor performance during dual task walking. Moreover, the time did not allow us to do a follow up once back home to correlate alterations with the risk of falling during activities of daily life.

CONCLUSION

Finally, the information obtained in this study may have important consequences in terms of prevention of falls, and may subsequently be used to support procedures and rehabilitation techniques specific to the tasks examined in the study. In particular, the reduction of speed resulted a valuable strategy for maintaining the same gait stability from a single to a dual task, but subjects with stroke may overestimate their ability resulting exposed to a higher risk of fall during dual task. For these subjects, rehabilitative protocols should be also based on acquiring an awareness of the actual locomotor abilities [36]. In particular the task used in our study revealed a for assessing the patients' performances could be included into a rehabilitation training in which walking is combined with a cognitive task (the difficulty of which could be progressively increased). Also elderly people could benefit from a dual task walking training for increasing dynamic gait stability.

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Figure 1. Mean and standard deviation of percentage change of walking speed (black) and acceleration root mean square along latero-lateral axis (grey) during dual task with respect to single walking task for the five groups.

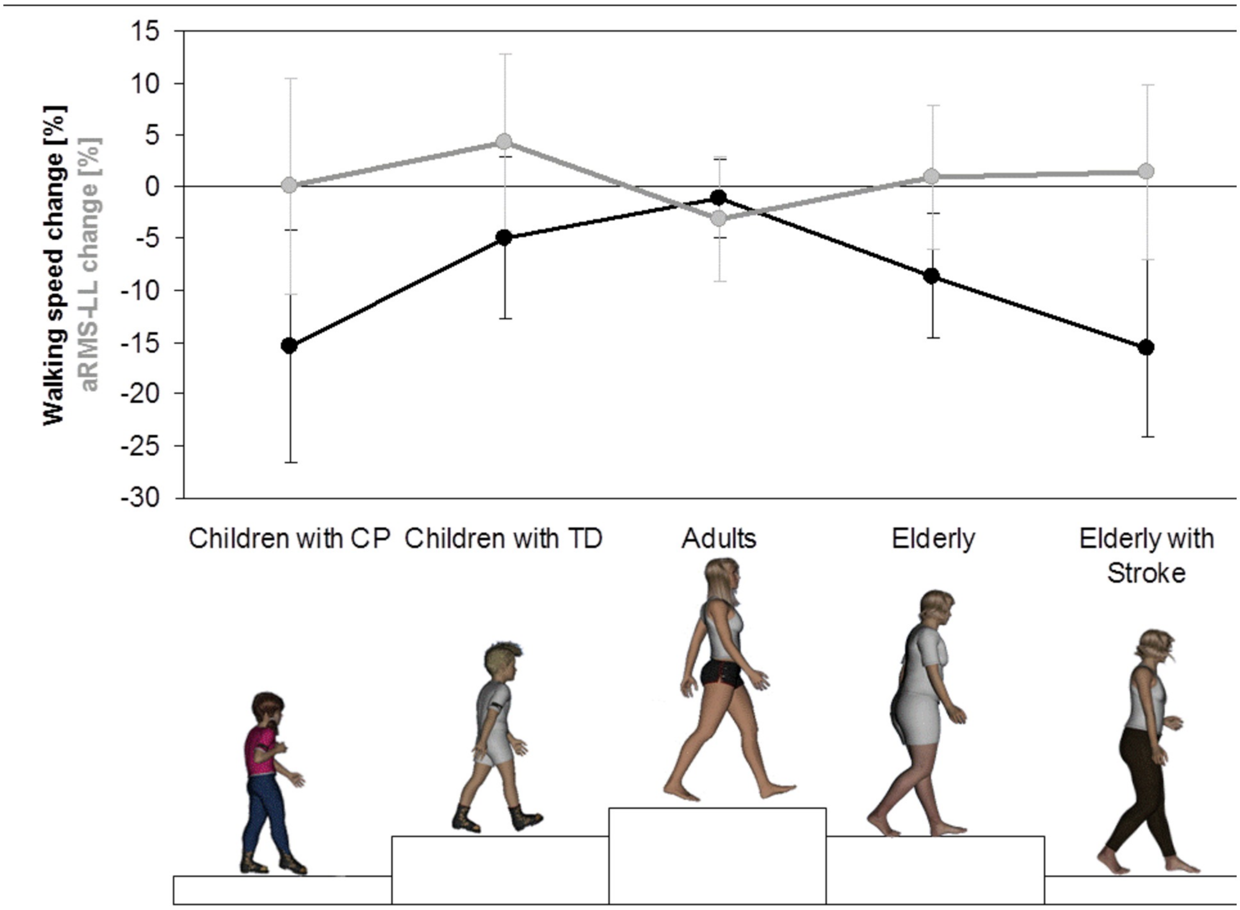
Figure 2. Correlation between percentage changes in acceleration root mean square along cranio-caudal axis (aRMS-CC) in dual and single task and Berg or Pediatric Balance Scale for elderly with stroke (grey) and children with cerebral palsy (black), respectively. Quadratic fit have also been reported.

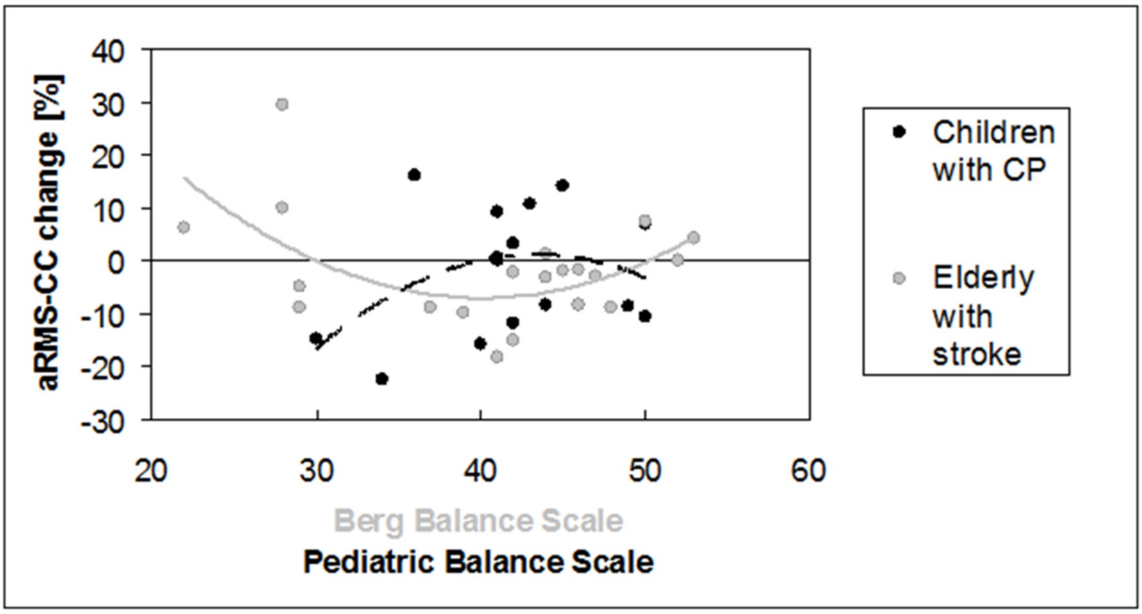
Group	**Children With CP**	**Children With TD**	**Young Adults**	**Elderly**	**Subjects with stroke**
N	15:5 diparesis, 4 right hemiparesis, 4 left hemiparesis, 1 ataxia, 1 tetraparesis	10	20	20	20: 10L (7 ischemic 3 hemorrhagic) 10 R (7 ischemic 3 hemorrhagic).
Age	6.40±2.56	7.00±2.54	23.80±3.00	68.60±6.14	68.73±7.07
Gender	8M, 7F	2M, 8F	12M, 8F	9M, 11F	14M, 6F
Clinical Assessment of stability	PBS=41.9±5.6 GMFM=92.7±6.7 GMFM-E=78.3±19.1	-	-	-	BBS=46.1±4.4 TS= 24.9±2.2 Tloc=11.0±1.2 Teq=13.9±2.0

Table 1. Demographical and clinical features of the 5 samples of enrolled subjects.

Correlation with changes in WS	**aRMS-CC**	**aRMS-LL**	**aRMS-AP**
Adults	**R=0.446,** **p=0.049**	R=0.312 p=0.181	R=0.246, p=0.296
Children	**R=0.716** **P=0.020**	R=0.448 P=0.194	R=0.493 P=0.147
Elderly	**R=0.613** **P=0.003**	R=0.156 P=0.500	**R=0.478** **P=0.029**
Children with CP	R=0.487 P=0.066	R=0.414 P=0.125	**R=0.555** **P=0.032**
Elderly with stroke	R=0.377 P=0.101	R=0.015 P=0.949	R=0.164 P=0.489

Table 2. Pearson correlation coefficients and relevant p-values computed between changes in speed and those in acceleration RMS along the three body axes for the five group of subjects.


Walking speed change [%]
aRMS-LL change [%]
15
10
5
0
-5
-10
-15
-20
-25
-30
Children with CP
Children with TD
Adults
Elderly
Elderly with Stroke


40
30
20
10
0
-10
-20
-30
aRMS-CC change [%]
20
30
40
50
60
Berg Balance Scale
Pediatric Balance Scale
● Children with CP
● Elderly with stroke