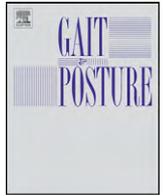




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Gillette Gait Index in adults

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ABSTRACT

Gillette Gait Index (GGI) is a very useful tool to assess gait abnormalities. However, it seems that it has only been validated in children with cerebral palsy. Nevertheless, the parameters used to compute GGI are not specific to children population. Our aim is to demonstrate that GGI could also be used to evaluate adults gait abnormalities. 44 adults (25 healthy and 19 pathological) participated to this study. Pathological subjects had a diagnosis of central nervous system pathology (6 with spinal cord injury and 13 with brain injury). We first, compared the kinematic parameter values of our healthy adult group to healthy children group in previous studies. It appears that those parameters' variability is a bit lower in adults, which makes the GGI more sensitive. Moreover, the GGI in adults is too much dependent on one parameter among the 16 proposed by Schutte et al. (2000), the "Time of Peak Flexion". Finally, the Edinburgh Visual Gait Score (EVGS) is correlated to GGI in children. To emphasize the relevance of GGI in adults, we have evaluated the correlation between EVGS and GGI in our pathological group. Those two parameters are indeed highly correlated. All these results allow us to conclude that the GGI computed with the 15 remaining parameters is a useful tool to assess gait abnormalities in adults.

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1. Introduction

Objective quantifying of gait ability has been a challenge in the past 10 years. In this field, the Gillette Gait Index (GGI), defined by Schutte et al. [1] has become one of the most popular indices in pediatrics clinical routine. This index is a tool used to measure pathologic gait severity and assess therapeutic outcomes [2] in children with cerebral palsy (CP). The GGI is a multivariate index combining 16 gait variables including temporal, spatial and kinematic parameters to derive a single measure of overall gait function. It estimates deviation of a patient's gait from a normal gait pattern. Among the 16 parameters it has been shown that one can be dropped out with no impact on GGI values [1]. However, to ensure GGI accuracy, two important factors must be taken into account. First, the average normal gait pattern must be set up with enough subjects [3]. Second, the reference and patient gait analysis must result from the same laboratory [4]. Aware of this, GGI can be considered as a gait analysis summary score in pediatrics [5]. However, it seems that GGI has been only used to study children's gait [5–8] and very often only with CP. In our knowledge, no global index is available for adult gait assessment what represents a gap in adult clinical practice.

We assume that the kinematic parameters used in GGI are not specific to children with CP and should be relevant in other neurological conditions. By this, we do not pretend that mean values of these parameters could not be slightly different in adults. We assume that they are also representative of the adults' gait. Romei et al. showed that the GGI is robust to categorize pathology, ranging from mild disorders to quadriplegia [9]. Such pathological conditions result in gait pattern which can be found in adult pathological gait. A gait assessment tool valid in both childhood and adulthood would be useful for patient follow-up and especially for transition to adult services for young people with disabilities.

Therefore, the main aim of our study is to see how the GGI could be used to assess gait abnormalities in adults with central nervous system disorders. As GGI has only been calculated in children till now, we will first need to compare children and adults gait in healthy populations. Indeed, the mean values of the kinematic parameters within the GGI and their variability could be different in those two populations.

Then, we will evaluate the relevance of each of the 16 GGI's parameters in pathological adult subjects.

Whatever the reason, 3D gait analysis is not always available in all rehabilitation centers. Hence visual gait analysis remains an important tool for clinician to quantify gait impairment when no alternative is available. The Rivermead Mobility Index is the clinical scale usually used to assess mobility but not gait in adult population with stroke based on a series of question and one visual observation [10]. No simple, complete visual assessment seems to exist for use in

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adult population. The Edinburgh Visual Gait Score (EVGS) is a recent scoring system for visual gait analysis, covering sagittal, coronal and transverse plane motion of the foot, knee, hip, pelvis and trunk. Each of 17 items is allocated a rating of 0, 1 or 2, depending on their deviation from normal [11–13]. It has been demonstrated that GGI and EVGS are correlated in CP children [14]. It seems that the EVGS has only been used for children’s gait assessment whereas EVGS items should be also relevant for adult population. EVGS could not be considered as a “Gold Standard”. However, even if none has been validated in adults, a correlation between EVGS and GGI in this population would emphasize both their relevance. Indeed, these indices are validated and correlated in CP children and none of them uses parameters specific to children.

2. Methods

2.1. Participants

A sample of 25 healthy participants with no lower limb orthopedic history (14 females, 11 males) and 19 pathological participants (11 females, 8 males) were recruited. They were all adults. Mean age was 33.6 years (from 22 to 57) for healthy group and 42.2 (from 15 to 63) for the pathological one. All participants signed an informed consent before their inclusion and the study conformed to the Declaration of Helsinki.

Moreover, participants were included in the pathological group only if they had a diagnosis of central nervous system pathology and were able to walk by themselves with or without assistive devices. Exclusion criteria for this group were recent (less than six months) surgery intervention or Botulinum Toxin injection in the lower extremity. Eight subjects were hemiplegic, three were paraplegic, three were tetraplegic, one had a cerebral palsy and four had a traumatic brain injury.

2.2. Experimental procedure

Each subject was asked to walk in straight line at his comfortable speed. Up to 10 walking trials were collected for each subject, this number depending on the fatigability for pathological subjects. As in previous studies, one representative gait cycle was chosen for each side. The path was about 10 m long and data were collected over the middle section. The walking cycle selected for evaluation was at least 4 m after the start in order to ensure that subjects did reach their actual comfortable speed. To ensure ecological conditions, subjects walked wearing their shoes. Indeed, even if it has been shown that there are very few differences in walking with or without shoes in healthy children [15], some of our pathological subjects did wear specific shoes or ankle-foot orthoses that need to be held by the shoe. And obviously, in pathological group, subjects who needed a walking aid and/or an orthosis used their usual devices.

They were all equipped with 16 markers placed on anatomical landmarks following the International Society of Biomechanics recommendations [16]. Kinematic data was recorded with a Vicon 370 optoelectronic system using six cameras cadenced at 60 Hz. Post-processing was performed using Vicon IQ 2.5 software. Lower body angles were computed using Wu et al. recommendations [16]. All kinematic data needed to compute the Gillette Gait Index was extracted from this 3D gait analysis. Computation of GGI was performed using Matlab 6.5 (Natick, MA, USA).

Subjects’ motion was also recorded using two synchronized video cams at 25 Hz. One is placed so that its optical axis is the same as the subjects’ mean path, the other one besides this path with a 90° angle. Even if the sagittal view is the most used to compute the EVGS, the frontal one is also needed for some few items (‘Foot rotation’, ‘Pelvis obliquity at mid stance’, ‘Knee progression angle’, ‘Trunk maximal lateral shift’ at least). Six experienced physiotherapists did calculate the EVGS for each pathological subject. The actual EVGS for each subject is computed as the mean of these six scores.

2.3. Comparison between healthy adult GGI parameters and reference values previously reported in healthy children

Three previous studies provide reference values for the computation of GGI [1,6,9]. The computation of GGI is based on each parameter mean and standard deviation in healthy population. Therefore, to compare our measurements in our healthy population to these previous studies, we need to compare both means and standard deviation.

As the 16 parameters have different measurements units, we need to normalize them to get dimensionless values. To do so, we first choose one study, among the four ones, as the reference study. Then, for any parameter, means and standard deviations are normalized using the corresponding standard deviation of the reference study.

Comparison of means is done by computing distances to the reference study. More precisely, let us denote $M_i(i)$ the mean value of the i th parameter of study s . Among these studies, we can choose one as the reference for which means are

denoted $M_{ref}(i)$, standard deviation $SD_{ref}(i)$. For any of the three other studies, absolute relative difference is computed as

$$ARD_{study}(i) = \frac{abs(M_{study}(i) - M_{ref}(i))}{SD_{ref}(i)}$$

Indeed, we wish to conclude that two studies are actually different if they do not have the same means. But, the error could be an over or an under estimation. Large overestimations combined with large underestimations would potentially lead to “no difference” if we do not compute the absolute difference.

Comparisons are made using a repeated measure ANOVA. If the normality test prior to ANOVA fails, we will proceed to ANOVA on ranks. Post hoc tests will be performed using Student–Newman–Keuls test.

2.4. Relevance of each of the 16 parameters in adult

To evaluate the relevance of each of the 16 kinematic parameters chosen by Schutte et al. [1], we use the same methodology. The principle is that for each of the 16 parameters, we do compute an alternative GGI that only takes into account the 15 others, excluding the one we want to evaluate. A correlation between the real GGI and this alternative one allows to quantify the relevance of the excluded parameter. A too low correlation coefficient will indicate that the parameter is not relevant; meaning indeed that the GGI is too much sensitive to this parameter.

2.5. Correlation of GGI and EVGS in adult

First, if the analysis of the 16 parameters indicates that some parameter(s) is (are) not relevant, GGI will then be computed only using the relevant parameters. To evaluate this new GGI in our adult population, we will compute the Pearson’s correlation coefficient between GGI and EVGS for each leg of each pathological subject.

3. Results

3.1. GGI reference values in healthy adults, comparison with previously reported values in children

Mean ages of the healthy reference population and the associated range are given in Table 1 for the three previous studies considered for comparison and ours.

Tables 2 and 3 respectively provides mean and standard values computed for each of the 16 parameters involved in the GGI calculation in three previous studies and in ours.

Whatever the study chosen as the reference one, no significant difference is observed between absolute relative differences of

Table 1
Mean age of healthy population and range in three previous studies and ours.

	Schutte 00	Romei 04	Assi 09	Ours
Mean age	10.5	14	10	33.6
Range	4.9–17.6	7–28	5–15	22–57

Table 2
Comparison between previous studies, involving children, and ours, involving adults, of mean values for the 16 parameters of GGI in healthy populations.

	Schutte 00	Romei 04	Assi 09	Ours
Time of toe off (% gait cycle)	61.87	58.36	58.09	62.60
Walking speed/leg length	1.43	1.63	1.52	1.57
Cadence (step/s)	1.94	1.91	1.88	1.87
Mean pelvic tilt (°)	9.26	9.43	8.1	–5.75
Range of pelvic tilt (°)	3.57	3.81	3.2	3.56
Mean pelvic rotation (°)	0.15	–0.78	–0.04	–0.12
Minimum hip flexion (°)	–11.14	–6.59	–5.1	–11.18
Range of hip flexion (°)	45	38.98	43.4	44.72
Peak abduction in swing (°)	–0.3	–0.16	–8	6.73
Mean hip rotation in stance (°)	10.91	2.03	31.9	–0.52
Knee flexion at initial contact (°)	6.83	6.24	8.5	9.42
Time of peak flexion (% gait cycle)	71.4	70.06	71.7	72.91
Range of knee flexion (°)	54.44	56.34	53.6	60.30
Peak dorsiflexion in stance (°)	13.31	11.68	17	15.97
Peak dorsiflexion in swing (°)	3.21	3.82	9	10.41
Mean foot progression angle in stance (°)	–9.76	–11.26	–8.4	1.84

Table 3
Comparison between previous studies, involving children, and ours, involving adults, of standard deviation for the 16 parameters of GGI in healthy populations.

	Schutte 00	Romei 04	Assi 09	Ours
Time of toe off (% gait cycle)	2.67	1.96	1.83	1.45
Walking speed/leg length	0.21	0.13	0.3	0.16
Cadence (step/s)	0.11	0.31	0.23	0.09
Mean pelvic tilt (°)	4.26	5.2	4	3.62
Range of pelvic tilt (°)	1.6	1.25	1.6	1.45
Mean pelvic rotation (°)	2.51	3.19	2.52	2.82
Minimum hip flexion (°)	6.75	6	6.5	6.29
Range of hip flexion (°)	5.15	4.24	4.5	4.26
Peak abduction in swing (°)	3.27	3.53	3.5	5.14
Mean hip rotation in stance (°)	7.33	8.98	14	8.25
Knee flexion at initial contact (°)	4.69	4.54	6.5	4.13
Time of peak flexion (% gait cycle)	2.7	1.85	2.3	1.09
Range of knee flexion (°)	10.59	4.6	8	4.19
Peak dorsiflexion in stance (°)	6.45	3.76	6.8	4.60
Peak dorsiflexion in swing (°)	4.88	4.08	5.6	4.55
Mean foot progression angle in stance (°)	6.46	6.5	6.7	5.10

means. In each of the four ANOVA tests (one for each study as the reference one), *p*-value is always larger than 0.6.

On the contrary, whatever the study chosen as reference, standard deviation is different between studies. The post hoc tests do show that in our study they are lower than any of the three others. In Romei et al. study, they are also lower than the two other ones. Median values when performing the comparison test with our study as the reference one are given in Fig. 1.

As in the three other studies in children, we do retrieve a mean value of GGI close to 15. In our case, in adults, this mean value is equal to 15.7. The range is between 6.9 and 33.8.

3.2. Relevance of each of the 16 parameters in pathological adults

When computed with the 16 parameters the minimal and maximal values of the GGI were respectively 54 and 7744.9 with a mean of 608.1 (SD = 1564.5).

Correlation coefficient between GGI calculated with the 16 parameters for each leg of each pathological participant and GGI computed excluding one parameter is always higher than 0.99 except when excluding "Time of Peak Flexion". In that case, correlation coefficient falls down to 0.45, i.e. determination coefficient (R^2) is equal to 0.2.

The GGI computation thus seems to be too sensitive to this parameter in adult population. This is emphasized when computing the ratios of standard deviations for each parameter between our pathological and healthy groups. This ratio is always lower than four except for "Time of Peak Flexion" where it gets up to 14.

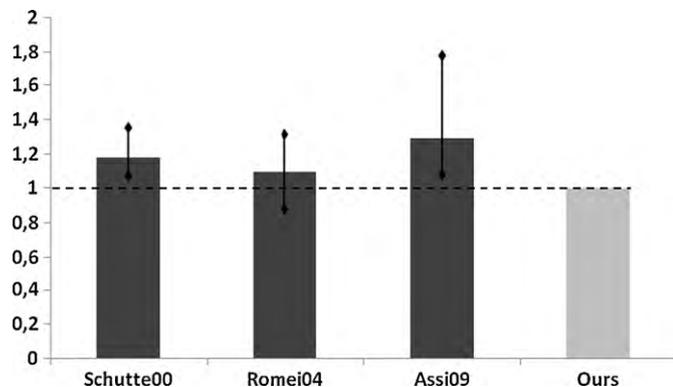


Fig. 1. Comparison of standard deviations between studies. Our study (in light grey) is the reference one. Box heights stand for the median value. Vertical lines indicates the 25 and 75 percentiles.

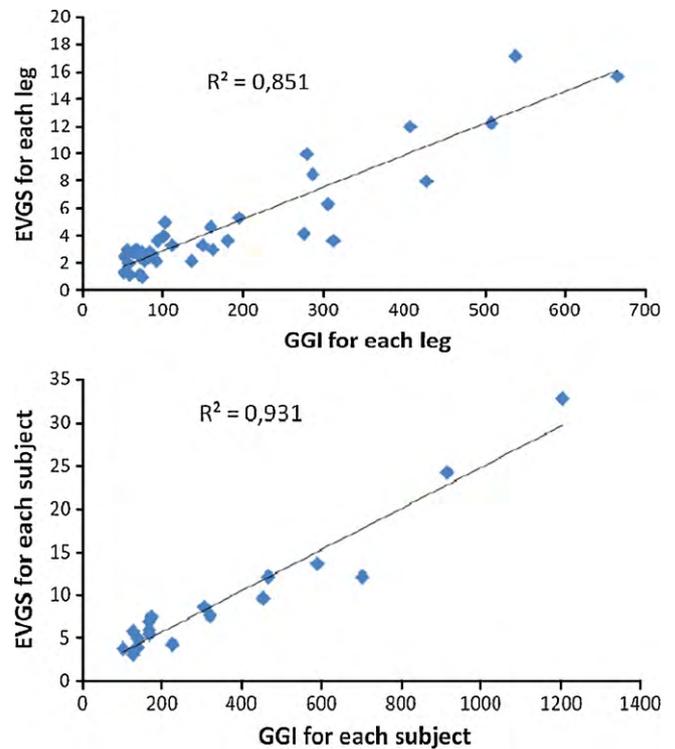


Fig. 2. Relation between Gillette Gait Index (computed without taking into account Time of Peak Flexion) and Edinburgh Visual Gait Score in pathological participants ($n = 19$). Top: correlation for each leg. Down: correlation for each patient (sum of results for both two legs).

This parameter is also the one which has the lowest standard deviation in our adult population with respect to any of the other previous studies involving children.

3.3. Correlation between GGI and EVGS in pathological participants

To compare GGI to EVGS, GGI is now computed with only 15 parameters, i.e. excluding "Time of Peak Flexion". Minimal and maximal values were respectively 50.6 and 665.5 with a mean of 174.1 (SD = 155.9). The correlation between this new relevant value of GGI and the EVGS is presented in Fig. 2. This demonstrates that the EVGS account for most of the GGI variance as the determination coefficient (R^2) reaches 0.85 when computed for each leg and 0.93 when computed for each subject (in that case, values of GGI and EVGS are the sum of the result for each of the two legs as it usually done when computing EVGS for one subject).

4. Discussion

The GGI is a valuable tool for assessing outcomes in children with cerebral palsy, but until now it has not been tested to evaluate adults' gait with central nervous system disorders.

Our study demonstrates that GGI can be used to assess abnormalities in adults' gait. Corridors of normality for the kinematic curves, defined by mean \pm 1SD were established to check the coherence of the results with regard to published data in the pediatric population. We show that the sensitivity of this index is even higher in adults than in children. Indeed, if the mean values of each of the 16 parameters chosen by Schutte et al. is not different in our healthy population than in healthy children groups in previous studies [1,6,9], the standard deviations are significantly lower. It is worthy of note that the older the subjects are, the lower the standard deviations are. Indeed, we do obtain the lower standard deviations in our fully adult group. Then comes, Romei et al. standard deviations

with their mid children and adult group (range is from 7 to 28). And finally, come the two other studies with subjects between 5 and 17.

Increasing the number of healthy subjects would lead to a better accuracy in computing the GGI, mainly by lowering the standard deviations [3]. However, the number of healthy subjects in the three previous studies was approximately the same (respectively 24, 25 and 36 subjects). Therefore, we must use a similar number of subjects. That is why our healthy group is made of 25 subjects. If we had a larger group, our lower standard deviations could have been the consequence of this number increasing and not only the age.

The mean values of three parameters ('Mean Pelvic Tilt', 'Peak Abduction in Swing' and 'Mean Foot Progression') are slightly different in our study compared to the three previous ones in children. First, we can involve a slightly different methodology. Indeed, these three values are dependent on the reference position. We choose to consider the ISB recommendations which could possibly be not exactly the same as those considered in the previous studies. Second, it is obvious that gait is a bit different in adults compared to children. These differences could possibly appear in these three specific parameters. For example, the structure of the hip slowly evolves during growth [17]. This could affect pelvic tilt and hip abduction. It is difficult to compute the relative contribution of these two explanations. However, children in Schutte et al. and Assi et al. studies [1,6] have the same age (between 5 and 15), but the "Mean Hip Rotation in Stance" is 11° in the former one and 32° in the latter one. This would be in accordance with the methodology hypothesis.

Obviously, GGI is too much sensitive to "Time of Peak Flexion" in adult population. The correlation between GGIs computed with the 16 parameters and with the 15 parameters excluding this one is very weak. Schutte et al. computed the correlation between the original index and indices calculated with one variable omitted, and demonstrated that the GGI appears to be relatively insensitive to its exact composition [1]. However, these authors observed that the lowest correlation was obtained when excluding "Time of Peak Flexion". Two combined reasons could explain this sensitivity in adults. First, the standard deviation of this parameter is very low in adults compared to children. Then, in pathological group some subjects have a longer stance phase, which delays the "Time of Peak Flexion".

That is why we assess that GGI has to be computed without this parameter. A high correlation between the new GGI (without "Time of Peak Flexion") and the EVGS demonstrates as Hillman et al. in CP children, the relevance of GGI in adults with central nervous system disorders [14]. Our determination coefficients are even higher than those obtained by Hillman et al. (0.85 vs. 0.69 when comparing the computation for each leg, and 0.93 vs. 0.79 when comparing the computations for each subject). Let us also denote that as them, we do obtain a higher correlation for subjects than for legs.

It would also be worth to evaluate the reliability and repeatability of the GGI and above all the EVGS, as it is partially subjective, in adults as it has been previously done in children [18].

It would probably be interesting to revise the set of parameters to consider to compute the gait index as this set could depend on pathology and age. However, we do think that the 16 parameters chosen by Schutte et al. are not specific of cerebral palsy and children. Our aim was not to try to define a new set but first to evaluate whereas it would be interesting to calculate a gait index such as the GGI in adults. A future work could be to define a better set that would probably not be that different.

Recently, Schwartz and Rozumalski described a new multivariate measure of overall gait pathology: the Gait Deviation Index (GDI) [19]. They demonstrated a strong correlation between GGI and GDI. This suggests that they are both measures of the same underlying construct, though the large spread at any given level indicates that they measure different aspects of gait pathology. As usual, the GDI was evaluated and validated in CP children. It could be interesting to validate GDI in adult population.

In conclusion, we demonstrated the relevance of the Gillette Gait Index in adult population. We believe that it could be used to broaden the field of objective gait analysis.

Conflict of interest statement

None of the authors have any financial or personal relationships or affiliations that inappropriately influence decisions, work, or manuscript.

References

- [1] Schutte L, Narayanan U, Stout J, Selber P, Gage J, Schwartz M. An index for quantifying deviations from normal gait. *Gait & Posture* 2000;11:25–31.
- [2] Gorton 3rd GE, Abel MF, Oeffinger DJ, Bagley A, Rogers SP, Damiano D, Romness M, Tylkowski C. A prospective cohort study of the effects of lower extremity orthopaedic surgery on outcome measures in ambulatory children with cerebral palsy. *Journal of Pediatric Orthopedics* 2009;29(8):903–9.
- [3] Tulchin K, Campbell S, Browne R, Orendurff M. Effect of sample size and reduced number of principle components on the Gillette Gait Index. *Gait & Posture* 2009;29(4):526–9.
- [4] McMullin M, MacWilliams B. Intersite variations of the Gillette Gait Index. *Gait & Posture* 2009;28(3):483–7.
- [5] Wren T, Do K, Hara R, Dorey F, Kay R, Otsuka N. Gillette Gait Index as a gait analysis summary measure: comparison with qualitative visual assessments of overall gait. *Journal of Pediatric Orthopedics* 2007;27(7):765–8.
- [6] Assi A, Ghanem I, Lavaste F, Skalli W. Gait analysis in children and uncertainty assessment for Davis protocol and Gillette Gait Index. *Gait & Posture* 2009;30(1):22–6.
- [7] Tervo R, Azuma S, Stout J, Novacheck T. Correlation between physical functioning and gait measures in children with cerebral palsy. *Developmental Medicine & Child Neurology* 2002;44(3):185–90.
- [8] Dobson F, Morris ME, Baker R, Graham HK. Gait classification in children with cerebral palsy: a systematic review. *Gait & Posture* 2007;25(1):140–52.
- [9] Romei M, Galli M, Motta F, Schwartz M, Crivellini M. Use of the normalcy index for the evaluation of gait pathology. *Gait & Posture* 2004;19(1):85–90.
- [10] Collen FM, Wade DT, Robb GF, Bradshaw CM. The Rivermead Mobility Index: a further development of the Rivermead Motor Assessment. *International Disability Studies* 1991;13(2):50–4.
- [11] Read HS, Hazlewood ME, Hillman SJ, Robb JE, Prescott RJ. A visual gait analysis score for a use in cerebral palsy: the Edinburgh Visual Gait Score. *Gait & Posture* 2002;S115–116 [16 ESMAC abstracts].
- [12] Read HS, Hillman SJ, Hazlewood ME, Robb JE. The Edinburgh Visual Gait Analysis Interval Training (GAIT) Scale. *Gait & Posture* 1999;10:63–4.
- [13] Read HS, Hazlewood ME, Hillman SJ, Prescott RJ, Robb JE. Edinburgh visual gait score for use in cerebral palsy. *Journal of Pediatric Orthopedics* 2003;23(3):296–301.
- [14] Hillman SJ, Hazlewood ME, Schwartz MH, van der Linden ML, Robb JE. Correlation of the Edinburgh Gait Score With the Gillette Gait Index, the Gillette Functional Assessment Questionnaire, and Dimensionless Speed. *Journal of Pediatric Orthopedics* 2007;27(1):7–11.
- [15] Oeffinger D, Brauch B, Cranfill S, Hisle C, Wynn C, Hicks R, Augsburgers S. Comparison of gait with and without shoes in children. *Gait & Posture* 1999;9(2):95–100.
- [16] Wu G, Siegler S, Allard P, Kirtley C, Leardini A, Rosenbaum D, Whittle M, D'Lima D, Cristofolini L, Witte H, Schmid O, Stokes I. ISB recommendation on definitions of joint coordinate system of various joints for the reporting of human joint motion—part I: ankle, hip, and spine. *Journal of Biomechanics* 2002;35(4):543–8.
- [17] Birkenmaier C, Jorysz G, Jansson V, Heimkes B. Normal development of the hip: a geometrical analysis based on planimetric radiography. *Journal of Pediatric Orthopedics B* 2010;19(1):1–8.
- [18] Ong AM, Hillman SJ, Robb JE. Reliability and validity of the Edinburgh Visual Gait Score for cerebral palsy when used by inexperienced observers. *Gait & Posture* 2008;28(2):323–6.
- [19] Schwartz M, Rozumalski A. The Gait Deviation Index: a new comprehensive index of gait pathology. *Gait & Posture* 2008;28(3):351–7.