Gait & Posture 40 (2014) 549–555

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Assessment of arm movements during gait in stroke – The Arm Posture Score

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ARTICLE INFO

Article history:
Received 7 July 2013
Received in revised form 22 May 2014
Accepted 26 June 2014

Keywords:
Arm Posture Score
Kinematics
Arm swing
Gait
Stroke

ABSTRACT

The purpose of the study was to apply the Arm Posture Score (APS) to a stroke population, since comprehensive measures to quantify arm swing in the affected and non-affected arms during gait are lacking. A further aim was to investigate how gait speed and upper limb function estimated by clinical measures are related to the APS in the stroke group. The APS is the summarized root mean square deviation (RMSD) from normal, based on kinematics. Four arm movements (sagittal and frontal planes) as well as six arm movements (incorporating transversal plane) were included in the calculation of APS, referred to as APS_4 and APS_6, respectively. The study population consisted of 25 persons with stroke and 25 age- and gender-matched controls. The APS measures were significantly different between the affected and non-affected arms, as well as between the affected arm and the non-dominant arm of the controls ($p \leq 0.001$). Spasticity significantly influenced both APS measures, while speed only had a significant effect on the APS_4. The APS measures correlated significantly to clinical measures of upper limb function. Both APS measures seem to be useful indices to quantify and discriminate between impaired and normal arm swing during gait after stroke. The variability of rotational arm movements needs to be studied further before considering the additional value of the APS_6 over the APS_4. When interpreting the APS, complementary kinematics should be taken into account, as the single value of the APS gives no information about the direction of the deviation.

1. Introduction

Approximately 80% of stroke survivors in Sweden experience walking problems three months post stroke [1]. Arm movements are often affected and recent research emphasizes that arm movements should be addressed during gait rehabilitation [2–4]. However, assessments used in stroke rehabilitation rarely evaluate arm movements during walking.

A person with stroke often moves the non-affected arm more than the affected arm during gait, a phenomenon that may be a direct result of the stroke or an adaptive strategy in order to facilitate walking [5,6]. Usually, the non-affected arm follows a reciprocal pattern (arm moves in the same direction as the contralateral leg) at comfortable gait speed, while the affected arm often shows an altered interlimb coordination [2,4]. Further, persons with stroke seem to have a reduced gait stability when disturbances occur [7]. About 20–30% of persons with stroke develop spasticity post stroke which is more common in the arms than the legs [8]. Spasticity and its associated consequences affect arm movements during walking [9], and is suggested as an important limiting factor for achieving normal walking speed [10].

Mature human walking involves rhythmic reciprocal arm swing and flexible coordination between pelvis and thorax. The pelvis–thorax coordination in the transverse plane evolves gradually from in-phase (rotations in the same direction) toward anti-phase (rotations in the opposite direction) with increasing gait speed [11,12]. Functionally, arm swing counteracts the rotational moment of the pelvis generated by the lower limb motion about the vertical axis of the body [13] and reduces the metabolic cost of walking [14–16]. Arm swing may be a result of passive dynamics rather than of active pendulums driven by shoulder muscles [13,14]. Nevertheless, the mechanisms and functions of arm swinging have still not been fully explained [4].

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http://dx.doi.org/10.1016/j.gaitpost.2014.06.014
0966-6362/

Instrumented 3D gait analysis is considered more accurate and precise than observational methods [9]. Complex kinematic gait data from the lower limbs can be summarized in overall indices, e.g., the Gait Profile Score (GPS) [17]. Although kinematic analysis of the upper extremity during gait is feasible, measures to quantify such data are lacking. Recently, the Arm Posture Score (APS) was introduced as an index to quantify arm movements during walking in children with cerebral palsy [18]. The APS is the root mean square deviation (RMSD) of four arm-movement variables from the sagittal and frontal planes, hereafter referred to as APS_4. The applicability of the APS_4 has been investigated in non-disabled adults and, further, the effects upon APS_4 by adding two rotational components (i.e., the APS_6) as well as the effects of gait speed on APS measures [19]. To the best of our knowledge, the APS_4 has not been tested on a stroke population. A potential limitation of the APS_4 may be that it does not include any rotational movements. It seems clinically relevant to include kinematic data from the transverse plane into the APS as persons with stroke often exhibit altered rotational movements in the shoulder and forearm [9]. The main aims of this study were therefore to investigate the applicability of the APS in persons with stroke by comparing them with non-disabled controls, and to investigate the effect on APS_4 by adding two rotational components (APS_6). Our hypothesis was that the APS would discriminate the movements of the affected arm from the non-affected arm, and the movements of the affected arm from the movements of the controls' non-dominant arm. Finally, we wanted to investigate if gait speed or arm function (estimated by clinical measures) were related to the APS in the stroke group.

2. Methods

2.1. Participants

Twenty-five persons with stroke (range 46–85 years) and 25 age- and gender-matched controls participated (for characteristics and clinical assessments see Table 1). The stroke group was recruited from two clinics. Inclusion criteria were adults aged 35–85 years who had experienced residual unilateral hemiparesis following an ischemic or hemorrhagic stroke at least 3 months post stroke and who were in a medically stable condition. Further, the persons with stroke were to be able to voluntarily lift each hand to their mouth, walk indoors without aids, and understand both verbal and written information. Exclusion criteria were impairments or diseases other than stroke that influenced gait ability. The controls were recruited among staff and acquaintances and through an organization for retired persons. Individuals with musculoskeletal or neurological movement problems were excluded. The study was approved by the Regional Ethical Review Board, and the participants gave written informed consent.

Table 1
Characteristics of participants in the stroke and control groups, mean and standard deviation.

Characteristics	Stroke group (n = 25)	Control group (n = 25)
Gender (male/female), n	15/10	15/10
Age (years)	68 ± 10	68 ± 10
BMI (kg/m^2)	27.1 ± 3.1	24.5 ± 1.7
Height (cm)	171 ± 8.1	174.4 ± 6.6
Hand strength (kg) aff/non-dom	23.6 ± 12.4	36.5 ± 9.3
Hand strength (kg) non-aff/dom	32.7 ± 9.3	38.2 ± 9.9
Handedness (right/left), n	24/1	24/1
Gait speed (m/s)	0.95 ± 0.31	1.30 ± 0.12
GPS aff/non-dom	6.4 ± 2.5	4.5 ± 1.3
Time since stroke (months)	25 ± 19	NA
Side of paresis (right/left), n	11/14	NA
Etiology (infarct/hemorrhage), n	21/4	NA
FMA UE score (aff)	49.6 ± 12.5	NA
Spasticity in the affected arm, yes/no	11/14	NA

Abbreviations: BMI, body mass index; GPS, gait profile score; FMA UE, upper extremity part of the Fugl-Meyer Assessment (max score 66); aff, affected arm (stroke); non-dom, non-dominant arm (control); NA, not applicable.

2.2. Data collection and procedure

This cross-sectional study took place in the U-motion lab, Umeå, Sweden. Kinematics were captured by a 3D motion capture system (eight cameras, 240 Hz, Oqus®, Qualisys Gothenburg, Sweden). The method is described in detail in a paper addressing non-disabled adults and some of those were controls in the present study [19]. Participants walked 10 m at a self-selected speed, for a minimum of six trials.

In addition to 3D gait analysis, the stroke group was tested for arm movement capacity using the following clinical assessments. (1) The *Fugl-Meyer Assessment (FMA)*, an ordinal scale with three response categories (scores 0–2) for each item, resulting in a maximum score of 66 for the upper extremity [20]. (2) The *Modified Ashworth Scale (MAS)*, a 6-point ordinal scale of graded muscle tone in a resting position ranging from 0 (no increase in muscle tone) to 4 (affected part rigid in flexion or extension) [21]. Muscle tone was tested for shoulder adductors, elbow flexors, and wrist flexors. (3) *Grip strength* was tested in both groups, measured with a digital hand dynamometer (Jamar®, US), and the mean of three trials was used. Moreover, all participants were classified with regard to handedness. The same two physiotherapists (GJ, GF) performed all the testing.

2.3. Calculations

All data were collected in Qualisys Track Manager (QTM, version 2.6; Qualisys, Gothenburg, Sweden). The majority of the calculations were based on six trials per subject. One person with severe stroke completed only four trials. A few gait cycles involving six participants had to be excluded because the camera system did not adequately capture the hand markers. Data were filtered at 15 Hz with a critically damped digital filter and processed in the software Visual 3D (Visual SD, v 4.94, C-Motion Inc., Germantown, MD, USA). The kinematic model used for calculations was constructed according to a Visual3D hybrid 6 degrees of freedom model. Anatomical frames were defined according to the International Society of Biomechanics recommendations [22]. Joint angles for wrist, elbow and shoulder were calculated using Cardan angles (X-Y-Z sequence), following the Joint Coordinate System by Cole et al. [23], a model traditionally used in gait studies.

The APS was based on kinematic data from 3D gait analysis according to the mathematical construction of the GPS [17]. The RMSD between the patient's data (a joint angle graph) and the average of the control data set was calculated over an entire gait cycle. For each kinematic variable this is referred to as a gait variable score (GVS). The GPS, which was also calculated, is the RMSD of nine GVS, and is a single index for the lower limb that describes overall gait pathology. Thus, regarding the upper limb, the APS_4 was calculated as the RMSD of *four* GVS_{ARM} (shoulder flexion/extension; shoulder abduction/adduction; elbow flexion/extension; and wrist flexion/extension) [18]. The APS_6 was calculated as the RMSD of *six* GVS_{ARM} (APS_4 plus shoulder internal/external rotation and forearm pronation/supination) [19]. The APS values are reported in degrees, and a higher value indicates a larger deviation from normal. The range of motion (ROM) for each joint movement was defined as the difference