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Timed Up and Go test: Comparison of kinematics between patients with chronic stroke and healthy subjects

Céline Bonnyaud[a,*], Didier Pradon[a], Isabelle Vaugier[b], Nicolas Vuillerme[c,d], Djamel Bensmail[e], Nicolas Roche[a]

[a] Inserm Unit 1179, Team 3: Technologies and Innovative Therapies Applied to Neuromuscular Diseases, UVSQ, APHP Service de physiologie et d'exploration fonctionnelle, Hôpital Raymond Poincaré, 92380 Garches, France
[b] Inserm CIC 1429, Hôpital R. Poincaré, AP-HP, Garches, France
[c] Univ. Grenoble Alpes Laboratoire AGIM, La Tronche, France
[d] Institut Universitaire de France, Paris, France
[e] Inserm Unit 1179, Team 3: Technologies and Innovative Therapies Applied to Neuromuscular Diseases, UVSQ, APHP Service de Médecine Physique et Réadaptation, Hôpital R. Poincaré, AP-HP, Garches, France

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ABSTRACT

Understanding locomotor behavior is important to guide rehabilitation after stroke. This study compared lower-limb kinematics during the walking and turning sub-tasks of the Timed Up and Go (TUG) test in stroke patients and healthy subjects. We also determined the parameters which explain TUG sub-task performance time in healthy subjects. Biomechanical parameters were recorded during the TUG in standardized conditions in 25 healthy individuals and 29 patients with chronic stroke using a 3D motion-analysis system. Parameters were compared between groups and a stepwise regression was used to indicate parameters which explained performance time in the healthy subjects. The percentage difference in step length between the last and first steps was calculated, during walking sub-tasks for each group.

Speed, cadence, step length, percentage paretic single support phase, percentage non-paretic swing phase, peak hip extension, knee flexion and ankle dorsiflexion were significantly reduced in the Stroke group compared to the Healthy group ($p < 0.05$). In the Healthy group, step length and cadence explained 91% of variance for Go and 86% for Return (walking sub-tasks), and none of the parameters explained the Turn. Previous study in patients with stroke showed that the same parameters explained the variance during the walking sub-tasks and balance-related parameters explained the Turn. The present results showed that step length was differently modulated in each group. Thus the locomotor behavior of patients with stroke during obstacle circumvention is quite specific in light of the results obtained in healthy subjects.

1. Introduction

The gold standard technique for gait analysis in stroke patients involves recording straight-line gait using a three dimension motion analysis system [1]. This does not reflect locomotion during daily life. Previous studies of gait have shown that different motor strategies are used by healthy subjects, depending on the environment [2,3]. These include altering gait speed without altering course to avoid collision [4], modifying step length prior to stepping onto an obstacle [5], changing step-width [2] and reducing gait speed during obstacle circumvention [3].

The Timed Up and Go test (TUG) is a clinical test of functional gait routinely used to assess locomotion in stroke patients [6,7]. TUG performance is slower following stroke [7,8], however, little is known regarding the motor strategies used by patients. Biomechanical analysis of each sub-task has thus been recommended [9,10]. A recent study determined the spatiotemporal and kinematic parameters that were most related to the walking and turning sub-tasks of TUG performance in patients with stroke [11]. However, this study did not include healthy control subjects. Other studies have shown that trunk and ankle kinematics, vertical kinetics and temporal coordination are altered during sit to stand and sit to walk tasks following stroke [12–14]. A difference in the

* Corresponding author at: Laboratoire d'analyse du mouvement Inserm 1179, Hôpital Raymond Poincaré, 104 Bld Raymond Poincaré, 92380 Garches, France.
E-mail address: celine.bonnyaud@rpc.aphp.fr (C. Bonnyaud).

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head anticipation distance (the distance between the real turn point and the point where the head started to turn) during turning in the TUG has also been found between stroke and healthy subjects [15]. However, data are lacking regarding locomotor adjustments during oriented gait and obstacle circumvention in patients with stroke compared with healthy subjects. This is important because sensory-motor function following stroke alters the biomechanics of gait [16–18]. Moreover such information would guide rehabilitation to improve the quality of gait.

The first aim of this study was to compare spatio-temporal and kinematic parameters during the walking and turning sub-tasks of the TUG between patients with stroke and healthy subjects. We hypothesized that gait parameters during the TUG would be lower in patients with stroke compared to healthy subjects since it is known that spatio-temporal and kinematic parameters are reduced in straight-line gait following stroke [19–22]. The second aim of this study was to determine the parameters which explain TUG sub-task performance time in healthy subjects. We hypothesized that step length and cadence would be particularly related to the performance time since they are related to the speed.

2. Method

2.1. Subjects

Twenty nine patients with chronic stroke-related hemiparesis followed in our rehabilitation unit (mean age 54.2 ± 12.2 years), and twenty five age-matched healthy subjects (mean age 51.6 ± 8.7 years) were included in this study. Calculation of the effect size and the statistical power (95%) using previously published data [7,8] showed that the sample size was sufficient to support our results [23]. To be included, patients had to have had a single stroke, be over 18 years old and able to perform several TUG tests without assistive devices. The healthy subjects had no history of neurological or orthopedic disorders. Patients were excluded if they were medically unstable or if they had other neurological or orthopedic disorders that might interfere with test performance. Subject characteristics are shown in Table 1. This study was conducted in accordance with the ethical codes of the World Medical Association. All subjects provided written informed consent. The local ethics committee approved this study.

2.2. Clinical assessment

Patients with stroke underwent a clinical examination which included sensation and proprioception using the Nottingham Sensory Assessment, spasticity (quadriceps, rectus femoris, hamstring and triceps surae muscles) using the Modified Ashworth Scale and strength (hip, knee and ankle flexor and extensor muscles) using the Medical Research Council scale.

2.3. Experimental procedure

Each subject performed 3 trials of the TUG test in standardized conditions, previously published [11]. Participants were asked to stand up, walk 3 m, turn around a cone, return to the stool and sit down. Patients with stroke were instructed to turn towards their paretic side and healthy subjects towards their non-dominant side since the direction influences performance [24,11]. A previous study showed that standardized conditions reduce variability and allow easier interpretation of results [12]. No instruction was given concerning the side of the first step. The test was carried out at the subject's self-selected speed without orthoses or walking aids.

A motion analysis system with 8 optoelectronic cameras (Motion Analysis Corporation, Santa Rosa, CA, USA, sampling frequency 100 Hz) recorded the displacement of thirty-four reflective markers positioned on anatomical land marks according to the Helen Hayes protocol, as well as on the greater trochanter and the anterior superior iliac spine [25,26,11]. The signal was filtered using a low-pass Butterworth filter with a cut-off frequency of 6 Hz [27]. Anatomical frames defined from the reference standing position were used for the analysis of spatio-temporal and kinematic parameters. A MOtion Kinematics and Kinetics Analyser (MOKKA, Biomechanical ToolKit) was used to define the phases of the gait cycle (according to Perry [19]) and TUG tasks [28]. The three sub-tasks of the TUG were defined as in Bonnyaud et al. [11]: "Go" (first walking phase from the stool to the cone), "Turn" and "Return" (second walking phase back towards the stool). The same experimenter carried out all the analyses to ensure reliability [1].

The same parameters as in Bonnyaud et al. [11] were analyzed with Matlab (R14, The MathWorks Inc., Natick, MA, USA): (i) TUG sub-task performance defined by the time taken to perform each sub-task (Go, Turn and Return), (ii) spatiotemporal parameters: cadence, width, step length and percentage of single support phase (%SSP) and swing phase (%SP) for each limb, during the three sub-tasks, and (iii) kinematic parameters: peak flexion and extension of the hip, knee and ankle and maximal ankle dorsiflexion during swing phase, for each limb, during the three sub-tasks.

Our previous study showed that step length was the main parameter which explained performance during the walking sub-tasks preceding turn of the TUG in the Stroke group [11]. Modulation of step length provides an indication of how subjects prepare for a turn. It has been shown that reducing step length is a way to maintain stability [29]. We thus analysed the modulation of step-length during Go and the Return in both groups by calculating the percentage difference in length between the last and first steps, for each side, as follows:

$$\text{Percentage difference step length} = \frac{\textit{last step length} - \textit{first step length}}{\textit{first step length}} \times 100$$

2.4. Statistical analysis

We calculated the means and standard deviations of each parameter, for each subject during each sub-task. Data were normally distributed (Shapiro Wilk test). Independent *t*-tests were used to compare parameters between the Stroke and Healthy groups (the paretic limb of patients was compared with the weaker limb of healthy subjects and the non-paretic limb of patients was compared with the stronger limb of healthy subjects). Effect sizes

Table 1
Subject characteristics.

	Age (years)	Height (m)	Weight (kg)	Gender (m/w)	Time since stroke (years)	Hemiparetic side
Stroke group (n = 29)	54.2 ± 12.2	1.68 ± 0.09	73.2 ± 16.2	18m/11w	7.9 ± 5.7	12 right/17 left
Healthy group (n = 25)	51.6 ± 8.7	1.67 ± 0.1	65.6 ± 14.7	11m/14w	–	–

There were no differences in characteristics between groups (Student, p > 0.05). M: men; w: women.