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Original article

Variable compensation during the sit-to-stand task among individuals with severe knee osteoarthritis

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ABSTRACT

Background: Individuals with knee osteoarthritis (OA) show variability during the sit-to-stand (STS) task, so they may not perform the STS in the same way. This study aimed to determine whether individuals with knee OA have different strategies in performing the STS.
Methods: Participants with knee OA and able-bodied individuals underwent STS evaluation at a self-selected pace with use of a motion measurement system consisting of 12 cameras and 2 force plates.
Results: In total, 101 participants (57 women) with knee OA showed 3 main STS strategies. As compared with the 27 controls (14 women), 24 OA participants, compensated STS, showed greater trunk flexion (47.1° vs. 38.3°; $P < 0.01$) and trunk obliquity (4.6° vs. –0.8°; $P < 0.001$) when completing the STS task in the same amount of time as controls (2.4 vs. 2.7 s; $P = 0.999$). The second group ($n = 59$), inadequately compensated STS, also compensated with trunk flexion (47.7° vs. 38.3°; $P < 0.01$) and trunk obliquity (1.6° vs. –0.8°; $P < 0.001$) but took longer than controls (3.4 vs. 2.7 s; $P = 0.001$). The third group ($n = 18$), severe impaired STS, took an extended amount of time to execute the STS (6 s), with marked trunk flexion (59.2°) and obliquity (4.1°), so participants in this group were perhaps severely impaired in completing the STS.
Conclusion: This study identified 3 groups STS trunk strategies among participants with STS. Moreover, the data reveal a concise representation of the relations among strategy variables. The findings could be used to simplify the characterization of the STS among patients with knee OA and aid with follow-up.
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1. Introduction

The sit-to-stand (STS) task is the act of rising from a sitting position to a standing position [1,2]. STS is one of the most frequent and demanding activities in daily-life [3–5]. Individuals can perform approximately 60 STS motions each day, on average [6], each of which can use up to 95% of the knee extensor strength in older people when rising from low height chair [7].

Older people with knee osteoarthritis (OA) [8] usually experience difficulty in performing a STS, which can negatively affect their independence [4,9]. To perform STS, they need to simultaneously raise their body mass against gravity, maintain balance and cope with knee pain and dysfunction [4]. Recent studies noted that individuals with knee OA generally relied on altered movement patterns to perform the STS as compared with their able-bodied partners over the long term [9]. As example, individuals with severe knee OA have been found to have higher trunk flexion, 10% higher additional weight on the non-affected side, and lower (external) knee flexion moments on the affected side [9,10] than able-bodied people.

However, our previous studies revealed that participants with knee OA showed variability in several biomechanical variables used to characterize a STS task [9] or a gait pattern [13]. Indeed, individuals with the same level of knee OA severity [14] could use different strategies to perform a STS task (e.g., slow speed vs. fast

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speed). These results suggest that a better classification analysis, based on specific group characteristics, could help us understand how a functional task is performed. A classification analysis of a large dataset of clinical and biomechanical variables could be effective in identifying natural groupings and allow for a more concise representation of functional tasks studied.

The analyses of more specific classes of STS strategies could be useful for guiding clinical decision making to improve specific strategies for preventing and treating knee OA [15]. For example, concerning the effectiveness of total knee arthroplasty (TKA), studies have proposed to determine a preoperative screening protocol to identify patients for whom TKA would not be successful [16]. Indeed, nearly one third of individuals who undergo TKA still experience significant difficulty or are unable to participate in leisure activities [17].

Because knee OA is a multidimensional disease [18], many factors could be used to characterize the STS performed by people with this disease. From a clinical point of view, the best determinants are considered knee pain, knee function, body mass index (BMI) and general health status [2,18,19]. From a biomechanical point of view, spatiotemporal, kinematic and kinetic variables such as the time required to execute the STS, trunk displacement and knee moments have been used for investigation [9–11].

However, the extraction of pertinent information from a multidimensional dataset, especially to classify and explain a specific phenomenon, has been difficult because of the different nature of those variables (for a review, see Chau [20–22]). Rather than repeat several monovariate analyses proportional to the number of variables studied, a unique multifactorial analysis is preferred [23]. To our knowledge, multidimensional analyses have been conducted to better understand the gait pattern of individuals with knee OA [24,25] but not for a STS task. Among the multivariate techniques, multiple correspondence analysis (MCA) is a descriptive exploratory technique that aims to reduce and simplify data and to highlight the main associations, such as biomechanical and clinical variables, among individuals [26].

Therefore, the aim of this study was to determine STS classes based on a large dataset of clinical and biomechanical variables generated by individuals with severe knee OA. We hypothesized that with these variables, several concise strategies (i.e., classes) of STS could be identified. These classes could be used to better understand the different strategies that individuals with knee OA use to perform a STS and to improve clinical decision making.

2. Methods

We included individuals with symptomatic knee OA who were scheduled to undergo unilateral TKA. All presented debilitating knee pain with grade III–IV on the Kellgren & Lawrence scale [14]. Exclusion criteria were use of a joint prosthesis and a recent history of neurological or orthopedic disorders other than knee OA that could affect balance or gait. Able-bodied volunteers included as the control group had no knee pain and no history of neurological or orthopedic disorders that could affect gait or balance. The ethics committee of the University Hospitals of Geneva approved this study (no. CRE 09-307) and written informed consent was obtained from all participants.

The STS evaluation involved use of a 12-camera motion measurement system (Vicon MX3+, Oxford Metrics, UK) and 2 force plates (AMTI, Watertown, NY, USA) embedded in the floor to capture full-body motion and ground reaction forces under each leg, respectively. Reflective markers were placed at the lower limb level as described by Davis [27] and at the trunk level as described by Gutierrez-Farewik et al. [28]. The motion and force plate data were synchronized and sampled at 100 and 1000 Hz, respectively. Nexus software (Oxford Metrics, UK) was used to filter marker trajectories and analog data, and kinematics (lower limbs and trunk) and kinetics (lower limbs) data were computed by using the Plug-in-Gait model (Oxford Metrics, UK),

Because previous studies addressed the effect of chair arm and chair height [3,29], the STS was standardized as follows: all participants sat on a backless and armless chair with the chair height set to give both knee angles 90° of flexion. Participants positioned their feet at the same level and symmetrically in relation to the middle of the chair. However, no restriction was imposed for the choice of feet position in the transverse plane (toe in/out). Participants kept the same feet position between trials. They were asked to rise from the chair at their self-selected speed and instructed to keep their arms alongside their body and not use them to help rise up from the chair. Each participant completed 4 trials [9].

The beginning and end of the STS were determined by using the angular velocity of the trunk segment. The beginning of the STS (T0) was defined as when the velocity of the trunk initially became greater than 0 and the end of the STS (T2) as when the velocity of the trunk returned to 0 and stabilized to 0 [9]. Another intermediate instant, the seat-off (T1), corresponded to the instant when the buttocks left the chair, identified by the lowest position of both anterior pelvis markers [9]. Between T1 and T2, when there was no contact between the participants and the chair, was referred to as the STS suspension time (for detailed description of the STS movement see Turcot et al. [9]).

The trunk angular displacement corresponds to the angle between the trunk and the laboratory coordinate system. The knee moment corresponds to the moment between the thigh and the shank based on only the information of the force plates embedded in the floor. The joint angular displacements and the external joint moments having a flexing and adducting effect were defined as positive. The external joint moments were normalized for body weight (N/m/kg).

We chose 6 discrete biomechanical variables for their relevance to characterize STS deviation for participants with knee OA [9]: STS time (s), STS suspension time (s), trunk flexion max (°), trunk obliquity max on the non-affected side (°), knee flexion moment max (N/m/kg) and knee adduction moment max (N/m/g). These variables were determined by averaging values across the trials for each participant and were obtained by using a custom software developed with Matlab (MathWorks, USA) and the open-source Biomechanical ToolKit [30].

Pain and patient function were assessed by using the reduced version of the Western Ontario and McMaster Universities Arthritis Index (WOMAC) [31,32], with which each participant was asked to grade the level of pain or function on a 5-point Likert scale, ranging from 0 to 4. High values (maximum of 100) indicated less pain and better function. Quality of life was evaluated by the Medical Outcomes Study Short Form 12 (SF-12), a generic instrument for measuring health-related quality of life for specific physical and mental components [33,34]. The Physical Component Score (PCS) and the Mental Component Score (MCS) of the SF-12 were transformed so that a mean of approximately 50 and SD of 10 indicated the highest level of health [34].

Finally, the hip-knee-ankle (HKA) angle, a measure of lower limb alignment, was assessed by full-limb radiography [35]. The HKA angle and knee OA localization was determined by an experienced orthopaedic surgeon. The HKA varied from varus (< 180°) to valgus (> 180°).

The 6 biomechanical variables were transformed by using fuzzy window coding, which normalizes the data from different natures, simplifies the knowledge extraction process and increases data interpretability (for an example, see Appendix B). Contrary to a classical binary approach, in which only one value can represent a

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