A DYNAMIC STABILITY ANALYSIS OF THE SIT-TO-STAND TRANSFER

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SUMMARY

This study presents the use of a general measure, based on the estimation of a feasible acceleration space, to study the stability of sit-to-stand motions performed by volunteer subjects in different conditions (different seat heights, using or not a handle, motion in the sagittal plan or rise and exit on the left side of the seat). One of the main interests of this tool is that it allows studying configurations with non-coplanar contacts (e.g. when the subject used a handle). Up to now, such measure has been extremely rarely used to study human movements. Despite some limitations, results obtained in this study were coherent and interesting. It confirmed the stabilizing effect of a handle and showed that lateral motions may be more challenging as they include a transition on one foot only. Such results could be linked to the observed strategies employed by elderly drivers during car egress motions.

INTRODUCTION

Rising from a seat is a common task of our daily life. However, it is also a challenging task, in particular regarding the stability [1]. Indeed, the large changes in the contact areas between a person and its environment (notably at seat-off) combined with the relative instability of the final standing posture may be difficult to handle.

Traditionally these stability issues have been assessed using static criteria, like the projection of the Center of Mass (CoM) onto the base of support (BoS) [2]. Some authors propose to study the stability through dynamics variables, like the angular or impulse momentum of the CoM [3]. However, only few studied a formal dynamical stability criterion.

In addition, although stability criterion allowing considering non coplanar contacts (such as the use of a handle) have been developed for humanoids robotics and animation applications, they have been extremely rarely used and applied to human movement studies. For example, Barthélemy and Bidaud [4] proposed an interesting postural dynamic stability measure but demonstrated it for human motion only on one single sit-to-stand movement using only coplanar contacts.

Therefore, this study proposes to assess the stability of sit-to-stand motions using a general dynamic measure able to handle general contact conditions (non-coplanar contact, grasping…). It will thus: 1) demonstrate the usability and the limits, of such a measure; 2) provide insights about the influence of seat height, handle use and type of motion on the stability during sit-to-stand transfers.

METHODS

Seven healthy young male volunteer subjects were asked to perform 28 sit-to-stand motions in different conditions. The three controlled variables were: 1) the seat height (SH), set at 50%, 75% and 100% of the knee height; 2) the use or not of a handle (HU) located in front of them (in the sagittal plane at eye level); 3) the motion strategy, either frontal (motion in the sagittal plan) or lateral (rise and rotate to exit on the left side of the seat). A motion capture system and load sensors were used to measure the kinematics and contacts loads. Body segment inertia parameters were estimated based on regressions. Motions were then kinematically and dynamically reconstructed.

The measure of stability was based on Qiu et al. work [5], itself inspired from Barthélemy and Garsault [4, 6]. Contact constraints (friction, unilaterality, maximum grasping force…) were expressed as a polytope (extension of a polygon in n-dimensions). This polytope was then projected into the CoM acceleration space, considering the dynamics equation of the body reduced to a point-mass. For a given configuration of the body (position of the CoM, contact position and associated constraints) it resulted in a 3D volume, the *feasible acceleration space*, within which the CoM acceleration has to lie in order to satisfy the constraints and the dynamics of the simplify system.

Feet-ground and buttock-seat contacts have been modelled by 10 unilateral contacts (3 under each foot and 4 under the buttock) with a coulomb friction coefficient of 0.7. Handle grasp is modelled by 3 forces centred in the hand with maximum grasping force of 800 N. Changes in contact configuration (e.g. seat-off) were detected by inspection of the measured reaction forces. Polytope computations were performed using the MPToolbox [7].

The following measures were extracted: 1) R_{cheb}, the radius of the larger sphere that fit inside the admissible acceleration space, giving an idea of how challenging is the current state of the body in term of stability; 2) R_{res}, the minimal distance between the current acceleration of the CoM and the boundaries of the admissible space, which can be interpreted as a measure of stability margin.

The minimum value and the value at seat-off (usually considered as the most challenging instant of the motion) of these two variables were further used for statistical analyses. Data from trials with or without handle were separately analyzed by ANOVAs with factors Seat Height (50%, 75% and 100%) and Strategy (frontal or lateral). Results were reported significant for p-values inferior to 0.05.

RESULTS AND DISCUSSION

Figure 1 displays a typical feasible acceleration space. One can observe the drastic reduction of this space around the seat-off, particularly in the frontal direction (X axis). Figure 2 shows the time evolution of the R_{res} averaged across trials and subjects for each configuration. One can observe the obvious influence of the use of a handle, which increase the stability margin. Differences between frontal and lateral strategies arising after 50% of the motion can be attributed to the step of the right foot toward the left force plate during the lateral motions.

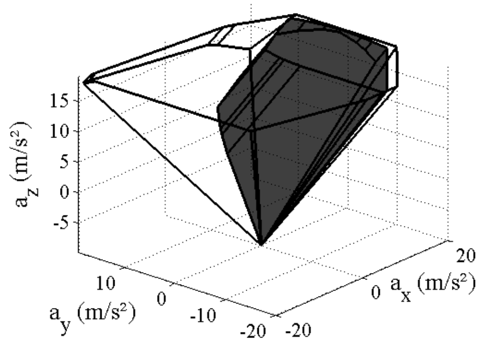

Figure 1: Example of 3D representation of the feasible acceleration space just before (transparent wireframe) and just after (grey polytope) the seat-off for a typical frontal motion, with low seat (SH = 50%) without using the handle.

For trials with handle, both Strategy and Seat Height 1) had no influence on R_{res} or R_{cheb} at seat-off; 2) but increased the minimum value of R_{res} and R_{cheb} between lateral and frontal motion and with Seat Height.

When the handle was not used, the Seat Height had no influence on R_{res} or R_{cheb}, neither at seat-off nor on the minimal values. However, the minimum value of R_{cheb} were smaller for lateral motion than for frontal one (similarly as for trials with handle), corresponding to the step of the right foot (see Fig. 2D). However, the contact configuration at seat-off induced higher R_{res} and R_{cheb} for lateral motions than for frontal motions. Thus, while lateral motions required taking a step, they appear less challenging, in term of stability, at seat-off than frontal motions.

Although experiments were performed on young healthy subjects, obtained results would be interesting to compare with data obtained on disabled persons, in particular study of car egress by elderly [8].

For the most challenging configurations (low seat height, without handle) the value of R_{res} was sometime found outside of the polytope (although always very close), revealing modeling inaccuracies. Among the possible sources of errors, one could mention the contact descriptions, notably the location of contact points under the feet and under the buttock. Another limiting hypothesis comes from the simplified point-mass model used, which means that the rotational accelerations of the body are neglected. This hypothesis is particularly limiting for challenging configurations around the seat-off, where subjects tend to use the rotation of the upper body to compensate the decrease of the feasible acceleration space. This should be improved in the future. Nevertheless, the very small distance outside of the feasible space observed, combined with the fact that it is usually reported that subject are very near to the stability limit just after seat-off, tend to support that the current measure provides coherent results.

CONCLUSIONS

This study presented the use of a general stability measure on sit-to-stand motions performed by volunteer subjects in different configurations. This general measure allows studying configuration where the subjects used a handle, i.e. with non-coplanar contacts. Although this measure provided interesting results, it had some limitations which would be interesting to overcome in the future.

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With Handle		Without Handle	
Frontal	Lateral	Frontal	Lateral

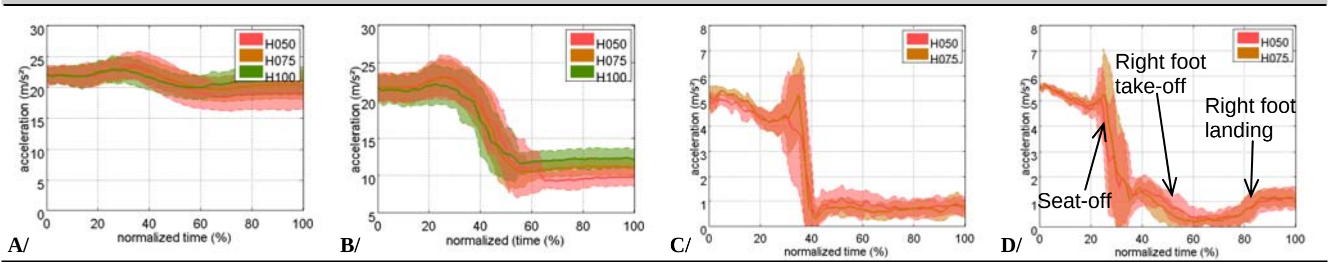

Figure 2: R_{res} averaged across subjects and trials for each experimental configuration. Note that the vertical range changes between plots A and B (configuration with handle) and plots C and D (configuration without handle).