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Impact of Spatial Hindrance on Sit-to-Stand and Exit Strategies of Low Mobility Passengers

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Abstract— aircraft cabin is considered as a hostile environment for low mobility passengers, especially around seat interaction. Improving air travel experience, and more specifically sit-to-stand (STS) and seat exit could be done through digital human modeling, and there is a need for a first description of STS ergonomic in order to properly design such a model. An experimental setup was built that reproduces actual aircraft cabin geometry, associated with motion capture devices, to describe STS and exit strategy of low mobility passengers. Results showed that subjects relied on several sequential strategies composed of hand positions and trunk bending. Those results will help to define model parameters for future large scale studies based on simulation, to improve accessibility of aircraft seats.

Keywords—sit-to-stand, aircraft seat, low mobility passengers, ergonomic

1. Introduction

The increasing proportion of elderly among European population makes essential to improve product usability for them, as 65+ y.o. people should reach 17% to 30% of total population, and 80+ y.o. from 5% to 12% [1] in 2060. As one consequence of ageing and possible diminution of functional abilities, one can expect also an increase of low mobility people. In addition, the United Nation World Travel Organization considers tourism access for low mobility people as a key element of a sustainable and responsible tourism politic, and therefore encourages the non discrimination of accessibility to air travel [2].

Those recommendations came in addition to international regulations on non discrimination for air travel [3], which obliged flight transportation companies and flight industry to improve air travel experience of low mobility passengers. Nonetheless current air travel conditions are still considered as bad and need improvements [4-7]. Aircraft cabin elements seem particularly in need for a focus, such as the seat, identified as the least satisfying element of the air travel experience, and thus as a good target for improvements [6][8].

Seat position in the aircraft cabin brings a challenge on itself, as hindrance limits the physical possibilities of any passenger, making seat accessibility a good starting point for improvement. In detail, the hindrance brought by the front backrest prevents the possibility of using classic sit-to-stand (STS) and stand-to-sit strategies [9-10]. For instance, the forward trunk bending is limited by the front backrest, and the passenger has to compensate with one or two upper limbs, by placing them on available supports (top of the front backrest, on the armrest, on their own backrest behind, etc.). In the case of passenger with reduced mobility, the use of alternate STS strategies, uncommon and thus less practiced, in an encumbered environment, may induce risks of STS failure, and even falling.

One solution could be to engage into the modification off current seat, or design additional helping devices to improve seat accessibility, by the mean of parametric study on seat geometry, hindrance parameters, and their impact on STS. Such a study would require to recruit numerous subjects, and to study their STS strategy on several biomechanical, behavioral and ergonomic parameters, at the cost of a great deal of trials per subject. An alternative methodology has already been tested, known as digital human model, for car seat accessibility [11]. But previous any design of a human model, one has to define global parameters of such a model, such as number of dimensions (2D/3D), number of degrees of freedom, starting position, failure criterions, etc., and undertake a first description of STS in encumbered environment.

The present study proposes a first investigation around the modification of sit-to-stand strategy of low mobility passenger due to encumbered environment, within air travel context.

2. Material and Methods

A. Recruited population

A total of five subjects were recruited for the present study. Selection criterion was defined as walking difficulties from injury, amputation or surgery, but still able to walk without additional device.

All subjects underwent a TUGO test (Test Up and GO), as well as Unipodal test in order to assess functional capacities. Lower limb pathologies of subjects were (table 1): TA (Tibial Amputation), FA (Femoral Amputation), KP (Knee Prosthesis), HP (Hip Prosthesis), AH (Spine Arthrodesis following spinal disc Herniation), and BKT (Bilateral Knee Tendinitis).

Table 1: subject description

	S1	S2	S3	S4	S5
Sex	H	H	H	H	H
Age	52	60	56	58	28
Weight (kg)	78	73	90	70	80
Height (cm)	168	170	175	170	177
Pathology	TA	FA	GP+HP	AH	BKT
TUGO test	9.62	10	20.5	16	12.83
Unipodal test	4	4	4	3	4

B. Experimental setup

The geometry and environment of an actual Air France aircraft cabin (Boeing 777-200) was rebuilt in the biomechanical laboratory (fig. 1), using actual aircraft seats Z300 (Zodiac Seats France) and aircraft carpet. Seat forward spacing (pitch) and lateral spacing were extracted from actual LayOut Passenger Arrangement (LOPA) of Air France aircraft: pitch was 80cm and aisle width was 50cm.

Fig. 1: experimental set-up with all seat rows and wall

The platform is fully modular: it can be tilted up to 3° in order to reproduce the natural tilt of a commercial aircraft during flight, and an additional seat rank can be optionally placed in front and another one at the side of the targeted seat. Finally, a vertical wall can be placed in front to reproduce the geometric situation of the first row of the aircraft cabin.

C. Studied configurations

In order to study several actual seat positions within an aircraft cabin, the platform configurations are sorted based on hindrance level, high or low, corresponding to the possibility for the passenger to bend the trunk when standing/sitting, such as done on a normal chair:

- Low hindrance: target, target seat with wall in front, target seat with side seat (fig 2, left)
- High hindrance: target seat with seat in front, target seat with seat in front and side seat (fig 2, right)

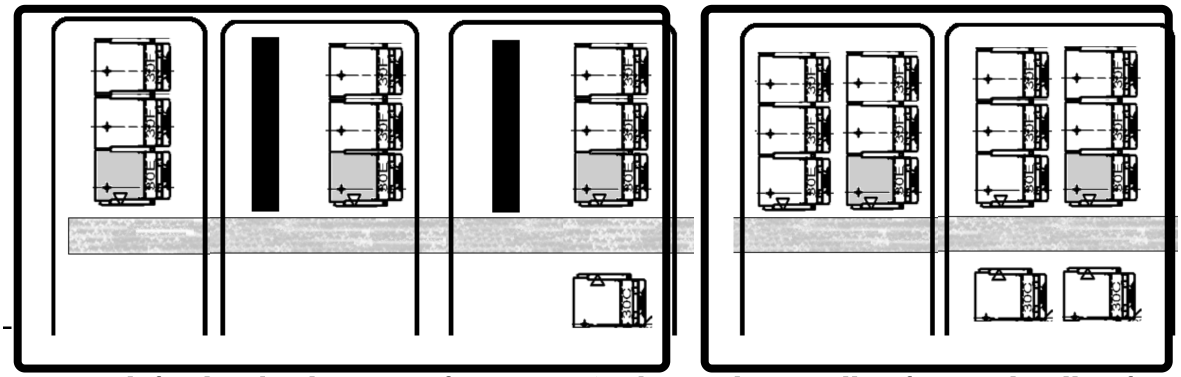

Fig. 2:left = low hindrance configurations (with seat alone, wall in front and wall in front with side seat), and right = high hindrance configurations (backrest in front, backrest with side seat), with target seat in gray

D. Experimental protocol

Subjects stood still at 2 meters from the target seat, waiting for instructions. Subjects were asked to walk at self selected pace toward the seat, and sit the most natural way possible. Once sit, subjects were asked to rise, exit the seat and walk at self selected pace to the starting position. Each trial was done once with 0° of horizontal tilt, and once at 3° of horizontal tilt.

E. Movements capture

Subjects motion was recorded by three synchronized digital video cameras, placed around the target seat. The three view angles were chosen in order to bring as most information as possible regarding sitting/standing strategy, such as hand positions, upper limbs actions and trunk position.

In addition, a set of four reflective markers were placed on each subject on the forehead, both shoulders (acromion) and sternum, in order to allow the tracking in 3D of the trunk and head. Markers are associated with a 10 cameras motion capture system (VICON) that gives the 3D position, with submillimetric accuracy, of each marker, with a framerate of 100Hz. Trunk lateral bending is then given by the calculation of rotation angle (Euler angle) around the postero-anterior axis in sagittal plan, with positive values corresponding to a bending toward right, i.e. toward exit.

3. Results

A. Hand resting positions

Video analysis showed that subjects always used their upper limbs and their hands to rise, for both low and high hindrance configurations: hand resting positions were armrests and front backrest. Over all configurations and subjects, hand resting positions during sit-to-stand were:

- Right hand 66.3% on armrest and 30.7% on front backrest
- Left hand 45.4% on armrest and 53.8% on front backrest

When simultaneous left/right hand positions were analyzed, it was possible to define 4 possible bimanual combinations: both hand on armrest, both hands on front backrest, right hand on armrest with left hand on front backrest and left hand on armrest with right hand on front backrest (fig. 3). Amongst those 4 bimanual combinations, only both hands on armrests was actually observed (with 86%) during STS under low hindrance configurations, with remaining (14%) observations corresponding to single hand resting. Under high hindrance configurations (fig 4), bimanual combinations were mostly both hands on armrests (75%), right hand on armrest with left hand on front backrest (62%), and both hands on front backrest (17%).

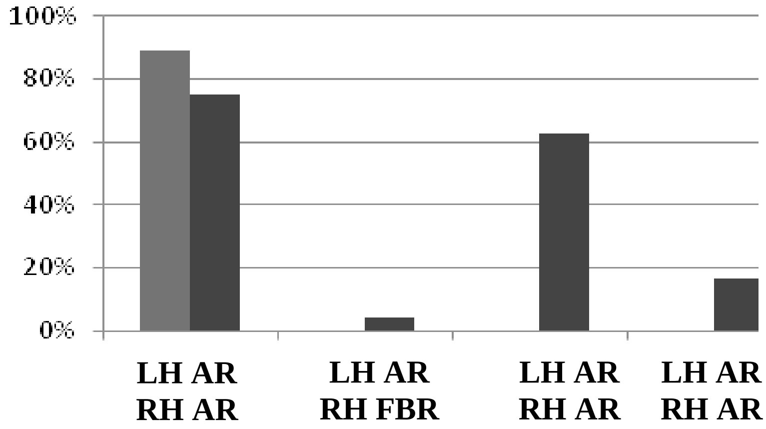

Fig. 3: bimanual combinations (in % of total observation) for low hindrance configurations (gray) and high hindrance configuration (black), with LH = left hand, RH = right hand, AR = armrest and FBR = front backrest

Figure 4 shows also that for high hindrance configurations, the sum of values is higher than 100%, because some subjects used a succession of several combinations during STS: 44% of both hands on armrests combinations were followed by right hand on armrest with left hand on front backrest, ant 17% were followed by right hand on armrest with left hand on front backrest and then both hands on front backrest.

B. Head displacement

Effect of hindrance level on head displacements were given by the 3D tracking of the forehead reflective marker in the sagittal plane (fig 4).

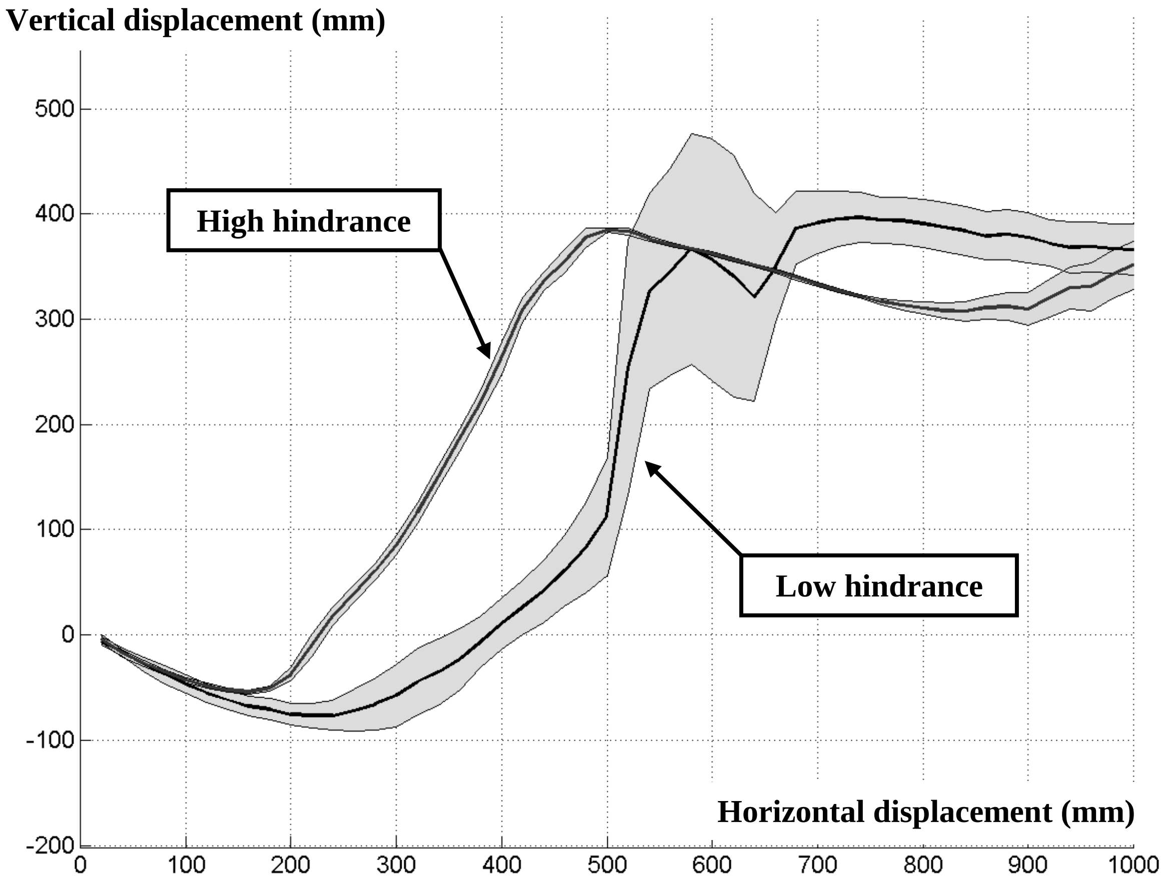

Fig. 4: example of head trajectory of one subject (vertical vs horizontal), for low and high hindrance configurations, with mean value in bold and +/- standard deviation in gray

Figure 4 shows an example of the effect of hindrance on head trajectory: whereas the subject used classic STS strategy [8-9] under low hindrance configurations, head rising trajectory was more vertical under high hindrance configurations. In addition, standard deviation corridor was thinner, meaning that hindrance limited the possibilities of the subject, who relied on a single trajectory.

C. Trunk lateral bending

Within the frontal plane, the effect of hindrance on STS strategy is analyzed from the lateral bending of the trunk. No lateral bending was observed under low hindrance configurations: subject rose using a very symmetrical trajectory. For high hindrance configurations, two major behaviors were observed: 4 subjects showed large lateral bending angle toward exit, whereas the last one rather small lateral bending angle. Figure 5 presents an example of lateral bending during STS under high hindrance configurations, for two representative subjects: subject 1 rose and exited the seat with very little lateral bending, whereas subject 2 rose and exited with much larger lateral bending (maximum mean of 32° toward exit).

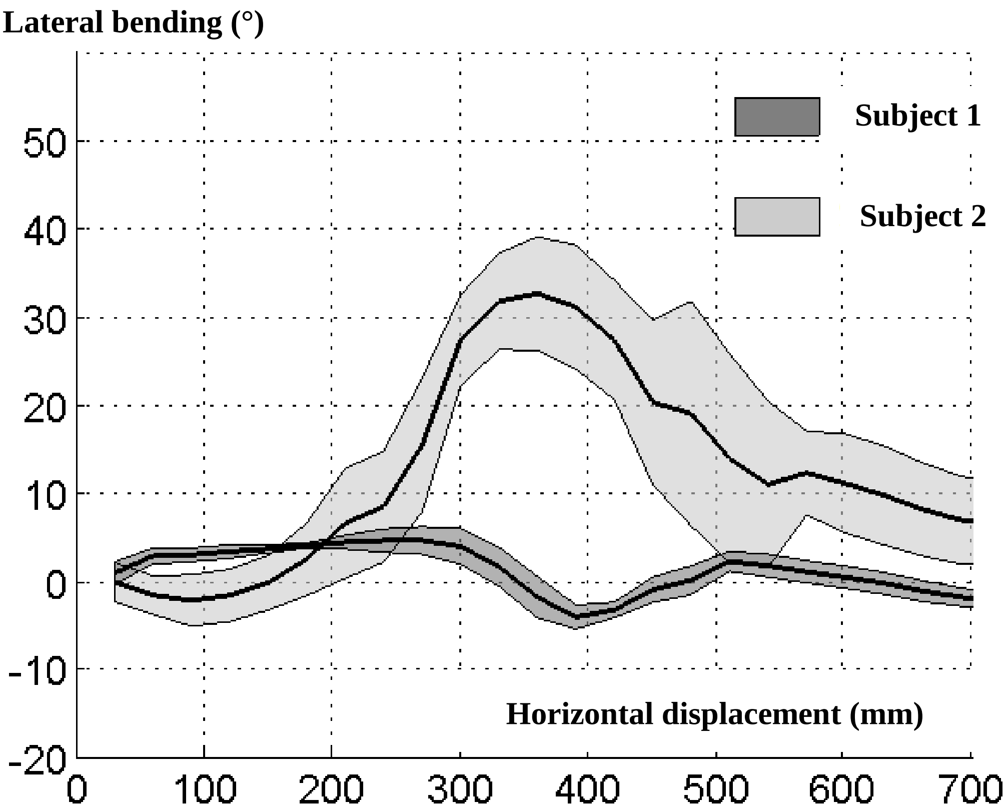

Fig. 5: lateral bending (positive values toward exit) under high hindrance configurations (mean in bold -/+ SD), for subject 1 (dark gray), and subject 2 (light gray)

Over all high hindrance configurations, subjects that rose with large lateral bending angle showed maximum angle of 35.4° +/-11.3°, and subject that rose with little lateral bending showed maximum of 6°+/-1,5°.

D. Chronologic aspects and STS strategies

Combined analysis of sequential combinations of hands resting position, trunk displacements, and lateral bending lead to the identification of 3 major STS/seat exit strategies (fig. 6):

- Strategy 1: both hands on armrests, the subject rises with little lateral bending and releases both hands simultaneously

- Strategy 2: right hand on armrest and left hand on front backrest, subject rises and exists with large lateral bending toward exit
- Strategy 3: both hands start on armrest (as strategy 1), subject rises with lateral bending toward exit, then releases left hand and lends it on the front backrest (as strategy 2)

Fig. 6: illustration of strategies 1, 2 and 3

4. Discussion

Results showed that subjects relied on several supports for rising and exiting from an aircraft seat, using both armrests under low hindrance configurations and 3 different strategies under high hindrance configurations: both hands on armrests, right hand on armrest and left hand on front backrest, or a sequence of those two strategies.

In order to propose a digital human model to investigate hindrance impact on Sit-to-stand from aircraft seat, those observations are fairly important, especially the sequential strategies: in order to include such behaviors, the model would have to accept several positions, as well as a criterion to switch from a position to another one. More specifically, the model would have to determine why a change of strategy should occur, and if it concludes to a strategy failure, seat modification or device design could results from it, in order to prevent such failure.

In addition, lateral bending (toward exit) showed by most subjects during raising and exiting from the aircraft seat implies that a digital human model cannot be in sagittal plane only: as a consequence, such model would be in 3D, with enough joints and segments to allow tridimensional kinematics.

Any modifications that could result from a model based study should minimize mechanical efforts as well as prevent any risk of falling. Actually, no subject of the present study fell during trials, as all of them could walk without devices. Thus, falling risks that come from STS strategies should be deeper investigated with additional subjects with less walking capacities, in order to validate and extend the present observations.

That point was already mentioned by a previous study [8]: recruitment of low mobility people was so difficult that the research team finally recruited elderly instead. If the low number of subjects of the present study cannot lead to reasonable statistical analysis of observed strategies, hand position combinations were similar to those already observed in comparable situation [8]: both hands on armrests or armrest/front backrest association. It is worth noticing that younger subjects from [8] mainly rose with both hands on armrests: a digital human model could confirm that such strategy is linked to higher functional capacities, which cannot be used by low mobility passengers, as suggested by the results of the present study.

Finally, the present study brought an additional limit to the low number of subjects, with the unicity of the studied seat: indeed, comparable previous work [8] included the middle seat and not only the aisle seat. Subjects could then rise and then laterally shift along the row to exit, whereas subjects of the present study could rise and exit in a single movement, mixing vertical and lateral displacement (and lateral bending). As a consequence, a digital human model should include two starting positions: from the aisle seat, and from the middle seat, with STS being merged with exit for the first, and a three steps (STS then translation then exit) for the second.

5. Conclusion

The present study brought a first description of sit-to-stand and exiting strategies of low mobility passengers in an aircraft cabin environment, under low and high hindrance configurations. Those observations lead to the determination of three different strategies, which will help to design a proper digital human model for larger scale experimentations, with a need for additional trials to build the database that feed the model. Such a model will be used to investigate hindrance impact on STS strategies, especially on biomechanical needs, in order to propose design improvements for aircraft seats or design of helping devices.

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