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\*Corresponding author: Marta Díaz-Boladeras, Rambla Exposició, 59, Neàpolis building, 08800 Vilanova i la Geltrú, Spain  
E-mail: [marta.diaz@upc.edu](mailto:marta.diaz@upc.edu)

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## BIOMEDICAL ENGINEERING | RESEARCH ARTICLE

# Perceived distress in assisted gait with a four-wheeled rollator under stress induction conditions

Marta Díaz-Boladeras<sup>1\*</sup>, Xavier Llanas<sup>1</sup>, Manuel Fernandez-Carmona<sup>2</sup>, Andreu Català<sup>1</sup>, Cristina Urdiales<sup>2</sup>, Marta Musté<sup>1</sup>, Elsa Pérez<sup>1</sup> and Àlex Barco<sup>1</sup>

**Abstract:** In assisted ambulation, the user's psychological comfort has a significant impact not only on acceptability of mobility aids but also on overall gait performance. Specifically, in the case of rollators, negative states such as distress may result in balance loss, inefficient manoeuvres, and an increased risk of falling. This paper presents a pilot study to investigate the effect of distress on rollator assisted navigation. To achieve this goal, a novel test protocol is proposed to assess distress while walking with a rollator, using the Self-Assessment Manikin (SAM) questionnaire. First, the participant completes a standardised visual stress induction test and fills in a SAM questionnaire on the dimensions of arousal and valence, to establish personal benchmarks. Then, they complete a course consisting of four navigation tasks with different levels of difficulty that affect the rollator manoeuvrability, filling in a SAM questionnaire after each task. An experiment including 25 healthy



Marta Díaz-Boladeras

### ABOUT THE AUTHOR

Marta Díaz-Boladeras At the Research Centre for Dependency Care and Autonomous Living (Universitat Politècnica de Catalunya) Marta Díaz-Boladeras has a PhD in Psychology and is head of the UX-Lab; Xavier Parra is doctor in Computer Science; full professor Andreu Català, has a PhD in Physics and leads the Centre; Marta Musté and Elsa Pérez have PhD in Industrial Engineering and Alex Barco has a PhD in Telecommunications. The group's research activities include ICT systems design for health and well-being, assistive technologies, wearable and intelligent sensors, social robots and human-robot interaction, artificial intelligence, human activity recognition, biomechanics, user experience and engineering education. At the University of Málaga Manuel Fernandez-Carmona has a PhD in Telecommunications and full professor Cristina Urdiales is a doctor in Telecommunications and in Computer Science, and member of the Institute of Mechatronics. The group's key research interests include assistive robotics and shared control, ambient assisting living, and wireless sensor networks.

### PUBLIC INTEREST STATEMENT

Psychological comfort and stress may have a significant impact on rollator-assisted ambulation, not only on acceptability but also on gait performance, balance and fall risk. This paper presents a pilot study to quantitatively assess the impact of distress while walking with a rollator. To achieve this goal, a novel test protocol has been designed, implemented and tested. The test includes four navigation tasks with different levels of difficulty in terms of rollator manoeuvrability. Besides, participants complete each task under different contextual stressors. To assess the perceived stress, the participant fills a validated self-assessment questionnaire after each task. The purpose of this study, which belongs to a broader research on smart mobility aids, is to identify and measure the user's response in assisted walk to train automatic stress detection systems based on psychophysiological measures gathered by wearable sensors.

volunteers has been completed. Our preliminary results show that stressors like uneven or sloping surfaces increase perceived stress, whereas the shape of the trajectory does not significantly affect stress. The ultimate purpose of this work is to validate a performance-oriented protocol to investigate the dynamics of stress response in assisted walk and to train automatic stress detection systems.

**Subjects:** Cognition & Emotion; Evaluation/ Program Evaluation; Disability

**Keywords:** stress assessment; assisted gait analysis; emotion elicitation; stress induction tests; Self-Assessment Manikin

## 1. Introduction

More than 1 billion people in the world live with some form of disability, of whom nearly 200 million experience considerable difficulties in functioning (World Health Organization, 2011). The disability may also provoke collateral problems like depression symptoms, poorer quality of life, lack of socialization and loneliness. In extreme cases, these disabilities may lead to dependency or even institutionalization. Many people with disabilities have locomotion limitations (i.e. difficulty walking, or are unable to walk), especially among the oldest age groups, with the risk of limited walking capacity increasing with advancing age (Salminen et al., 2009). In Spain mobility difficulties were the most frequent type of disability with a rate of 54 per thousand inhabitants (INE, 2020). Mobility disabilities challenge autonomy: 33% of elderly people have problems even to move around a room (Peel et al., 2005).

People with mobility limitations can be provided with mobility aids to enable activity, rehabilitation, autonomy and participation. There is increasing evidence that assistive technologies such as mobility aids contribute to diminish dependence and need for support services in late life (Freedman et al., 2006; World Health Organization, 2011).

For people who can still walk, portable aids like rollators and canes enhance speed and balance, and are also used for rehabilitation purposes to recover functionality (Fernandez-Carmona et al., 2022). Ideally, mobility assistance should be perfectly adapted to the user's needs, condition and situation to provide the least possible amount of help in order to avoid loss of residual skills and disuse syndrome (Dobkin, 2009).

In this context, robotized rollators can adapt mobility assistance to the therapy requirements and the user's needs. Robotised rollators may automatically provide parameters of interest for gait analysis (Cortés et al., 2008; Frizera et al., 2008; Graf, 2009) such as step/stride time and length, or weight supported on the handles (Kulyukin et al., 2008), and also evaluate navigation factors such as the user's intention, goal and environment factors (Fernandez-Carmona et al., 2022). Robot rollators working under the shared control paradigm are the best way to adjust assistance to user needs and preferences, in both rehabilitation and daily living activities. To decide how much influence users should have in motion control, it is necessary to assess not only the navigation factors but also their condition, needs and affective states.

Negative feelings, emotions and attitudes during interaction with a mobility aid may have three main detrimental effects: reducing the user's wellbeing, reducing the acceptability and usage of the aid and a degradation of gait. These result in a lowering of rehabilitation outcomes eventually increasing the risk of fall. Therefore, by considering the subjective experience and the level of comfort/discomfort, the navigation and clinical outcomes can be improved. More specifically, active intelligent assistance devices would benefit from the continuous estimation of the user's psychological states (e.g. stress) to adapt assistance to their needs. However, stress assessment and automatic detection are difficult not only because of the multifaceted nature of stress but also because of the individual response to stressors.

The aim of this paper is to quantitatively evaluate the impact of distress on rollator users during navigation in order to provide a ground and a personalised baseline for stress recognition systems. To achieve this goal, a new experimental protocol including different ambulation tasks under different stressors has been designed and tested.

The remainder of this article is organised as follows: Section 2 reviews literature and related research; Section 3 states the research questions and objectives of the work; Section 4 covers the design of the study with users; results are presented in Section 5; in Section 6 findings and lessons learned are discussed; and finally, conclusions and future work are presented in Section 7.

## 2. Related work

In this section, relevant antecedents on automatic stress detection in assisted gait are briefly reviewed.

### 2.1. Subjective experience in assisted Gait

In walking with rollators, a user's subjective experience depends mainly on the perceived success in managing the frame (e.g. speed, trajectory and flow), according to the intended movement. On the other hand, anxiety and sudden emotions during gait may affect the gait patterns (Can et al., 2019) and interfere with mechanisms for keeping balance among the elderly. Based on the recall of perceived stress among patients that have had a pelvic fracture (Möller et al., 2009), conclude that stress has the potential to trigger falls and subsequent hip or pelvic fracture among autonomous older people. As far as we know, this is the first study to report a trigger effect of emotional stress on the risk for fall. However, further research is needed to clarify the underlying mechanisms that presumably balance difficulties and vision impairment in stress situation.

As observed in users interacting with robotised wheelchairs in shared control mode, a high difference between the human intent and the robot recommendation (i.e. disagreement) is expected to be related to user workload and frustration (Urdiales et al., 2011). In the case of active intelligent rollators able to provide physical feedback (Han et al., 2022), users may occasionally exert strong forces to "counteract" the trajectory as an intent to regain the initiative in case of disagreement with the robot performance. This struggle can result in inefficient navigation and dissatisfaction, and in extreme cases lead to distress and increased falling risk. Thus, it is important to define a methodology to detect and quantify distress in order to modulate the collaborative control of the robotised system (Urdiales et al., 2010).

### 2.2. Stress estimates

Although stress is a widely used term, it is elusive in its conceptualization. Stress is, or results in, a nonspecific response of the body to a change request or to any demand upon it. This response is defined by an activation of the individual cognitive and physiological resources, which can be triggered by an external (i.e. loud noise) and/or internal stimulus (i.e. threatening thought) (Schmidt et al., 2019). The pattern of response is complex, primarily physiological, but also with psychological, cognitive and behavioral expressions, triggered upon perceiving a significant imbalance between the demands placed upon the person and their perceived capacity to meet those (Campbell & Ehlert, 2012; Giannakakis et al., 2017; Schmidt et al., 2019).

Concomitant to the increase in activation, a subjective experience results from the appraisal of a stimulus as harmful and threatening. Accordingly, the quality of the emotional experience (e.g. hopelessness, helplessness, anger and anxiety) is tightly coupled with such cognitive processes as well as with response outcome expectancies (Ursin and Eriksen, 2004).

While stress always implies an increase of arousal or activation, the quality of the associated subjective experience can be pleasant such as euphoria or enthusiasm, or on the contrary, can be unpleasant, such as anxiety, fear or frustration. In this work, we explore the unpleasant stress or distress, defined in the two axes circumplex model (Larsen & Diener, 1992) by a high activation

(high level of arousal) and negative experience (negative valence) (see Figure 1). Moreover, we can distinguish between chronic stress and acute stress as the temporary state of activation triggered by a particular activity or event. In this work, we focus on the acute stress state triggered by events or situations that may occur during gait supported by a rollator.

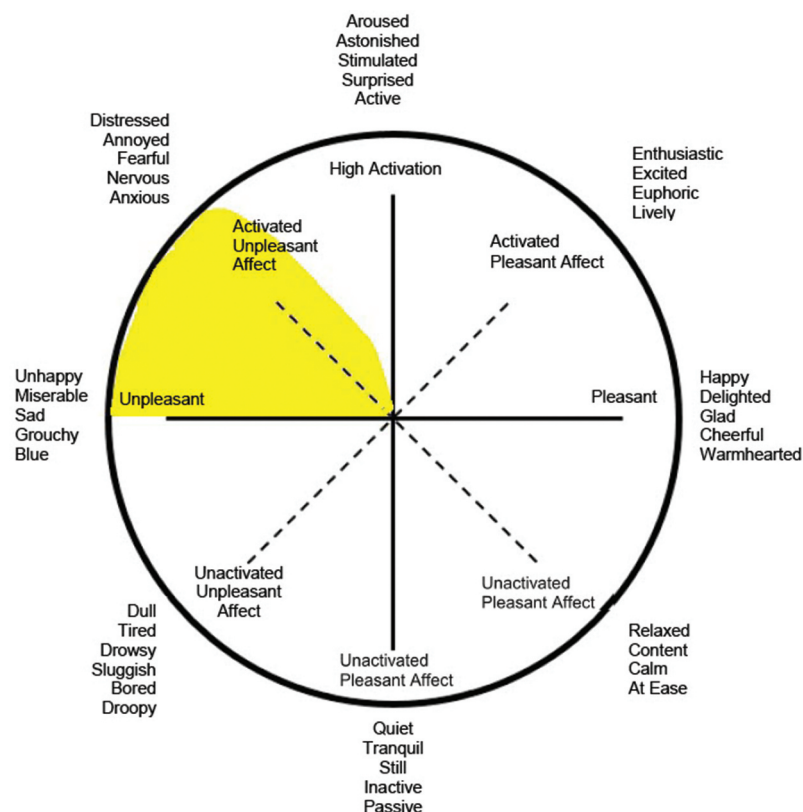
In our study the affective states included in the concept of stress are those placed in the left upper quadrant in the circumplex model of Larsen (Larsen & Diener, 1992). These states are characterized by both a high level of activation (high arousal) and an unpleasant subjective experience (negative valence) including distress, fear, annoyance and anxiety.

Given its multifaceted nature, the stress level can be assessed measuring any of its three observable dimensions: i) subjective experience, ii) hormonal and psychophysiological changes and iii) behavioural response.

The more common solution for continuous monitoring and automatic detection of stress consists of gathering related psychophysiological signals via unobtrusive wearable sensors. Signals of interest that can be monitored by these devices include Electro-Dermal Activity, Blood Pressure, Skin Temperature, Electromyogram, Respiration and Blood Volume Pulse (Can et al., 2019; Kocielnik et al., 2013; Sharma & Gedeon, 2012).

Because the validity of physiological response is crucial to automatic stress detection, investigation of the concurrence of psychophysiological signals with well-established stress measurement is required. For this purpose, self-report instruments such as the Perceived Stress Scale or the SAM questionnaire are employed (Can et al., 2019; Schmidt et al., 2019). This latter is the instrument used in our study. The SAM is an image-based affective rating system devised by Lang (1980) that features five expressive manikins depicting values along each of two dimensions of pleasure and

**Figure 1. A circumplex model of affect. The shaded area is the target of the present study (based on Larsen & Diener, 1992).**



arousal on a scale to indicate emotional reactions. A third dimension of dominance is less strongly related to affective states and often not included by researchers in the protocol. The scales range from a smiling, happy figure to a frowning, unhappy figure when representing the valence dimension. For the arousal dimension, SAM ranges from an excited, wide-eyed figure to a relaxed, sleepy figure. Subjects can rate their current emotional state by either selecting a manikin or marking in a space between two manikins, resulting in a nine-point scale. The SAM instrument is a relatively easy method for quickly assessing pleasure and arousal. Comparison studies with other relatively longer semantic differential scales indicate extremely high correlations for the factor scores of both dimensions, suggesting that the SAM quickly assesses these fundamental dimensions of emotion. The SAM data gathered to date also indicated that these ratings are stable when assessing either within- or between-subject reliability (Lang et al., 2008). Recent studies use the SAM questionnaire to assess the affective response of users while interacting with smart technologies (Baig & Kavakli, 2019; Liao et al., 2020; Swangnetr & Kaber, 2013).

However, the use of self-report scales as ground truth for stress detection is not straightforward. Though it would be expected that perceived and physiological stress measures are coherent, recent studies report divergences across these data (Liapis et al., 2015; Ren et al., 2014). Thus, more research is needed to examine the convergence of psychophysiological and self-reported measurements in controlled environments (Schmidt et al., 2019) and to understand the individual variability in reporting perceived stress. This work aims at contributing to this clarification.

### **2.3. Stress induction tests**

A common way to investigate stress in controlled environments is to induce stress in participants while measuring their response in any of its manifestations: perceived, psychophysiological and behavioural (Schmidt et al., 2019). In these stress generative settings, participants are asked to perform standardised tasks under different demanding stressors and to immediately report their experience (i.e. instant report). The most common standardized lab protocols eliciting stress include stressors such as a physically uncomfortable situation (e.g. Cold Pressor Test), a cognitive challenge (e.g. Stroop Color-Word Test), a social-evaluative threat (e.g. Sing-a-Song-Stress Test and the Trier Social Stress Test), a time pressure, or a combination of these (Socially Evaluated Cold Pressor Test) (Can et al., 2019; Menghini et al., 2019; Ollander, 2015; Ollander et al., 2017). Most of the tasks include social pressure where the participant is ostensibly submitted to evaluation and judgement on their performance, anticipating embarrassment, incapability or failure. Questionnaires integrated into the protocol should be used to verify that the desired affective states were successfully evoked by the situation. In order to generate labels in valence-arousal space, the nine-point SAM questionnaire based on iconic representations of emotions is frequently employed (Schmidt et al., 2019).

Another technique to elicit stress is visual induction that consists in presenting emotional visual or audio-visual content to participants which is a convenient and commonly used technique in academic research though with less ecological validity compared to other methods (Liao et al., 2020). For this purpose, several repositories of affective pictures and videos are provided by different academic institutions for easy referencing to be used in affective response research, such as the International Affective Picture System (IAPS) (Lang et al., 2008) that provides a standardized set of images with normative scores. The pictures vary from simple household objects to extreme pictures which cause arousal on individuals (e.g. mutilated corpses, erotic and violent scenes) (Akmandor & Jha, 2017; Can et al., 2019; Hui & Sherratt, 2018).

### **3. Research questions and objectives**

In the context of assisted gait research, we have identified three drawbacks in the more commonly used stress induction tests: i) some of them do not collect immediate response after the task or event and are more related to a state than to an instant response ii) in the visual tests, the participant is exposed to multimedia content and no activity is required—other than answering a question—so we cannot observe the effect of stress on behaviour (i.e. gait), and

finally iii) to our best knowledge, there are no stress induction tests that use exclusively walk-related situations as stimuli.

In this framework, we propose a novel stress induction test to assess the user stress during rollator assisted navigation. The proposal relies on establishing courses with different levels of difficulty and navigation-related stressors. The test includes four different navigation tasks while walking with a four-wheeled commercial rollator. Proposed stressors include walking blindfolded and walking with one braked rear wheel. Perceived stress during ambulation is measured by completing a SAM after each task. Besides, as different people may present different stress responses, volunteers are asked to previously complete a highly standardised stress induction test consistent with the sight of 30 pictures from the IAPS and answer the SAM questionnaire after each image.

### **3.1. Research questions**

According to the purpose of our research and from the literature reviewed, we establish the following research questions (RQ):

**RQ1** Does the SAM questionnaire provide a feasible and reliable measure of perceived stress in the context of assisted gait with a rollator?

**RQ1a** Is the SAM questionnaire scores in the study similar to those expected according to normative values in the standardized test IAPS?

**RQ1b** Is the SAM questionnaire sensitive to different gait tasks and gait stressors?

**RQ1c** Can scores on SAM be proposed as a ground truth for distress automatic detection systems?

**RQ2** Can the gait circuit developed be used to train automatic stress detection in the context of assisted gait using a rollator?

**RQ2a** Do the developed gait tasks elicit different perceived stress levels?

**RQ2b** Do the implemented manoeuvrability conditions affect stress levels?

### **3.2. Objectives**

The objectives of this work are:

- (1) A quantitative evaluation of stress during rollator assisted navigation under different conditions
- (2) Assessment of the feasibility and sensitivity of the SAM questionnaire to measure acute distress caused both by a conventional stress elicitation test (i.e. IAPS) and by the implemented gait test.
- (3) Evaluation of the SAM questionnaire as a ground truth for further training of automatic stress detection systems
- (4) Evaluation of the Images test to establish a baseline to adjust stress-level thresholds to individual stress response.

## **4. Methods**

### **4.1. Participants**

To test the protocol, we carried out a pilot study with 25 healthy participants: 14 women and 11 men aged between 20 and 67 ( $M = 50,2$ ;  $SD = 15,13$ ), recruited by convenience sampling among students, faculty and staff from the University Campus. All of them signed the informed consent to

participate. The sample size was based on the planned analyses: correlations with statistical relevance above 60% are required, therefore, accepting an alpha risk of 0.05 and a beta risk of 0.2 in a bilateral contrast, the number of volunteers necessary for this study is 20. Due to the single session test design, no follow-up losses were expected.

#### 4.2. Design

The *quasi-experimental* study followed a repeated measures design with two independent variables: exposure to images from the IAPS repository selected for their potential of inducing stress (i.e. low, neutral and high) and gait tasks through different navigation situations. The outcome variable analysed in this work is the subjective experience measured by user scores on the SAM questionnaire. The entire trials were video recorded for further behavioural analyses.

#### 4.3. Materials

##### 4.3.1. International Affective Picture System

Participants visualized 33 images selected from the IAPS repository including three for practice not evaluated, 10 for high stress potential, 10 for low stress potential and 10 neutral images, according to the images' normative values on *Valence* and *Arousal*. The order of presentation of the 30 images was random and was the same for all participants. After watching an image, participants responded using a pencil and paper to a 9-points version of the SAM, in the affective dimensions *Valence* (pleasure) and *Arousal* (activation). The participant can select any of the five figures presented for each dimension, or choose between any two figures, resulting in the 9-point rating scale. Ratings are scored such that 9 represents a high rating on each dimension (i.e. high pleasure and high arousal), and 1 represents a low rating (i.e. low pleasure and low arousal).

##### 4.3.2. Gait circuit

The *Gait Test* consists of a circuit of four paths—gait tasks—that participants walked with the assistance of a commercial four-wheeled rollator (Figure 2).

The tasks, with different levels of difficulty regarding the trajectory (i.e. straightforward or with turns) and the quality of the surface (i.e. smoothness and firmness), were the following:

- (1) *Ramp*: participants go up on one side and down on the other of an ascending and descending ramp
- (2) *Table*: participants walk around a round office table
- (3) *Mattress*: participant walk along on a soft surface made up of two viscoelastic mattresses covered with an artificial grass carpet that conceals the mattress completely
- (4) *L*: participants walk an L-shaped path with four rubber profiles placed crosswise to introduce surface unevenness.

After each task, participants completed the SAM questionnaire. Each participant completes the circuit four times.

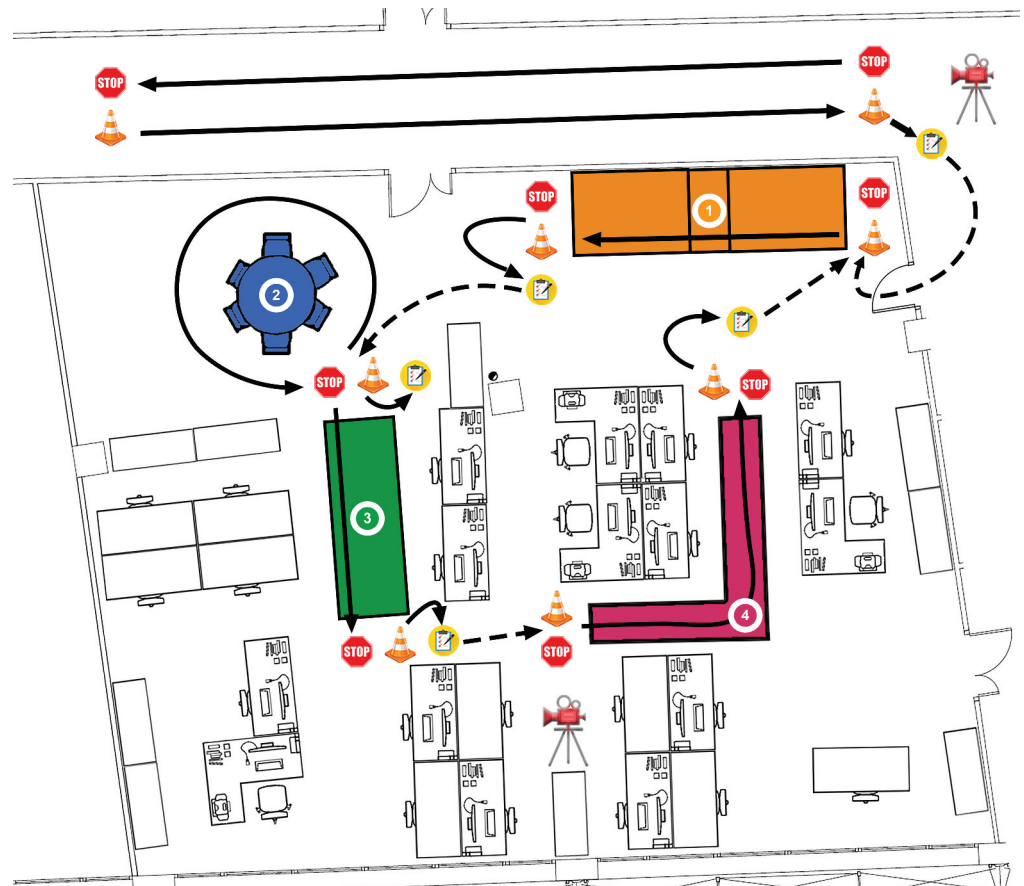
To create different levels of demand, two contextual stressors were defined: vision (full vision/blindfolded) and rollator manoeuvrability (braked/non braked). The layout of the circuit and the shape of the paths can be seen in Figures 3 and 4. The experimental conditions (i.e. combinations of course/stressors) are summarised in Table 1.

During the test, participants wore two wearable multi-sensor devices: the E4 wristband (EMPATICA) and the LifeMonitor vest (EQUIVITAL), for gathering psychophysiological data for further analyses. The entire trials were video recorded.

**Figure 2.** The commercial four-wheeled rollator Mobiclinic Escorial model used in the trials.



**Figure 3.** A sketch of the circuit's layout: from the bottom right and anti-clockwise Ramp, Table, Mattress and L. In the corridor out of the office -on the right- navigation task for practice, not analysed.



**Figure 4.** A partial view of the experimental setting with a participant walking on the soft surface in task mattress.



#### **4.4. Procedure**

Each trial consists of two parts, the IAPS Test and the Gait Test. On arrival at the laboratory each participant is welcomed by the conductor and briefed about the session. The information sheet and the consent form were delivered to the participant and were any doubts or concerns addressed. After reading the forms, the participant was requested to sign the consent to participate and to be video recorded. Once signed, the sociodemographic data were gathered, and the participant was walked to the test room.

##### **4.4.1. IAPS test**

The participant sat at a table in front of a wall screen, and the wristband was adjusted to the participant's wrist and checked. The participant was delivered with the SAM questionnaire booklet and a pen. The conductor read out loud the instructions of the IAPS test that are simultaneously displayed on the screen, encouraging the participants to ask for clarification if necessary. The test begins with three practice trials (not analysed), and if satisfactory, it is completed with the remaining 30 image trials. Every participant rated the same set of 30 pictures in the same order.

For each trial, the sequence was as follows: image presentation, scoring and recovery. First, an opening slide was displayed indicating the number of the image to be scored (6 s), secondly a red arrow appeared briefly to fix the participant's attention to the center of the screen (0.5 s), immediately after which the target image was displayed (6 s). The subsequent slide displayed a representation of the two-scale SAM questionnaire to indicate that the participant must mark the scores on the booklet (6 s). The trial was completed with a 20-s recovery time, during which a white screen was displayed.

**Table 1. Task features and experimental conditions (combination of stressors). Each participant performed Ramp under four different conditions, and Table, Mattress and L under two different conditions**

Task Type	Task Features										Conditions	
	Shape		Surface		Smoothness			Angle		Sloping	Blindfolded	Braked
	Turn	Straight	Firm	Soft	Smooth	Uneven	Flat					
Ramp		X	X			X				X	NO	NO
											NO	YES
											YES	NO
											YES	YES
Table	X		X			X			X		NO	NO
											NO	YES
Mattress		X		X		X			X		NO	NO
											NO	YES
L	X		X						X		NO	NO
											NO	YES

#### 4.4.2. Gait Test

Participants were explained what the gait test would consist of and allowed a practice trial including four gait tasks. These tasks consisted of walking in a straight line marked on the floor of a corridor, both without rollator assistance, the first time with full vision and a second time blindfolded. Then, the task is repeated this time walking with the rollator the first time with full vision and a second time blindfolded. After each task, participants were requested to answer the SAM questionnaire.

After practice, participants were addressed to the main office room and instructed to complete the first circuit starting with Task 1 *Ramp* (see Figure 2 for an overview of the experimental layout and *Materials* for the tasks description). The order of the gait tasks was always the same: *Ramp, Table, Mattress and L*. Task conditions in each circuit (sight/blindfolded and braked/no braked wheels) were randomly ordered to control the effects of fatigue, practice and persistence.

Each task had a numbered start point on the ground marked with a red cone where participants must stop, stand and wait for the facilitator signal to start the Task (start waiting point). When participants reach the *End* point, they are prompted to wait and after 4 s to take the SAM questionnaire. Once answered, they are asked to go to the next starting point at the next Task. There was a 15-s pause at the waiting point, in order to reduce the carryover effect of the reaction from one task to the next. If the task condition was to operate blindfolded, the participant was instructed to put a mask over the eyes. To start each gait task the conductor prompts the same instruction: “You can now go ahead to reach number X on the floor, where the cone is, stop there and wait”.

The sequence (wait, perform the task, stop and wait, complete the SAM, go to start point, wait and fulfil the task) was to be repeated for each of the four gait tasks.

Once the four circuits were completed, participants were invited to sit for debriefing, encouraged to discuss any additional information, thanked and walked to the exit.

#### 4.5. Ethical approval

The Ethical Approval for the whole procedure has been obtained from the Ethics Committee of the Technical University of Catalonia, in the board session of NaN Invalid Date , reference number 2020\_1.

### 5. Results

The following data were obtained in the trials: i) participants’ subjective experience (scores on the SAM questionnaires) in the IAPS test and in the gait test; ii) behavioural data (video recording of the whole session) not analysed in this paper and iii) psychophysiological data (from wearable sensors), not analysed in this paper.

#### 5.1. IAPS test

To obtain participants’ perceived stress baseline, we selected a set of 30 images from the IAPS repository. We expected that the responses correlate with the normative values of the IAPS (validity) and that there were differences in perceived stress across images of different potentials of generating stress (sensitivity).

As can be seen in Table 2 and Figure 5 the images selected by their high potential of eliciting negative stress (1, 3, 5, 12, 18, 21, 22, 23 and 28), obtained as expected simultaneously high scores in *Arousal* and low in *Valence* (i.e. distress response).

The variability between subjects measured by the range of scores (1 min-9 max) for both variables are the maximum (8) in 7 images for *Valence* and in 8 for *Arousal*. We can interpret

**Table 2. Descriptive statistics of scores on SAM, the normative Scores from IAPS, and the difference between gathered scores and normative scores**

Image	Valence						Arousal							
	Mean	SD	min	max	range	Norm	Dif	Mean	SD	min	max	range	Norm	Dif
1	1.42**	0.78	1	4	3	1.98	0.56	7.96**	1.22	5	9	4	6.94	-1.02
2	6.27	1.34	3	9	6	5.53	-0.74	3.65	1.64	1	6	5	3.72	0.07
3	2.04**	1.36	1	6	5	2.71	0.67	6.69**	1.58	4	9	5	5.75	-0.94
4	6.73	1.34	5	9	4	5.15	-1.58*	3.12	1.52	1	6	5	3.69	0.57
5	1.42**	0.85	1	4	3	1.91	0.49	6.92**	1.75	2	9	7	5.78	-1.14*
6	6.85	1.24	5	9	4	5.38	-1.47	2.81	1.77	1	7	6	2.63	-0.18
7	6.88	1.70	2	9	7	6.25	-0.63	3.27	1.72	1	7	6	3.32	0.05
8	6.69	1.64	4	9	5	6.81	0.12	3.38	2.06	1	7	6	3.05	-0.33
9	5.23	1.55	3	9	6	5.92	0.69	4.65	2.1	2	9	7	4.84	0.19
10	6.31	1.18	4	9	5	5.64	-0.67	3.81	1.8	1	7	6	3.36	-0.45
11	3.31	2.04	1	7	6	2.34	-0.97	5.00	2.01	1	9	8	5.76	0.76
12	1.24**	0.53	1	3	2	1.56	0.32	7.80**	1.73	3	9	6	6.79	-1.01
13	6.69	1.31	5	9	4	5.57	-1.12	4.54	2.48	1	9	8	4.9	0.36
14	5.00	1.50	1	9	8	5.80	0.80	3.50	1.93	1	8	7	3.24	-0.26
15	5.73	1.62	1	9	8	5.91	0.18	4.15	2.22	1	7	6	4.65	0.50
16	7.31	1.46	5	9	4	6.89	-0.42	3.92	1.93	1	8	7	3.09	-0.83
17	5.12	1.64	2	9	7	5.56	0.44	4.50	1.9	1	9	8	4.92	0.42
18	1.42**	0.78	1	3	2	1.68	0.26	7.27**	1.92	3	9	6	6.14	-1.13*
19	7.65	1.31	5	9	4	5.49	-2.16*	4.38	2.41	1	9	8	4.74	0.36
20	5.92	1.85	1	9	8	5.43	-0.49	5.00	2.35	1	9	8	5.02	0.02
21	1.35**	0.83	1	4	3	1.31	-0.04	8.04**	1.62	2	9	7	6.91	-1.13*
22	2.31**	1.64	1	7	6	1.95	-0.36	6.38**	2.31	1	9	8	5.95	-0.43
23	1.96**	1.30	1	5	4	3.10	1.14	6.92**	1.59	4	9	5	5.89	-1.03*
24	5.38	1.78	2	9	7	5.87	0.49	3.88	1.8	1	7	6	4.81	0.93

(Continued)

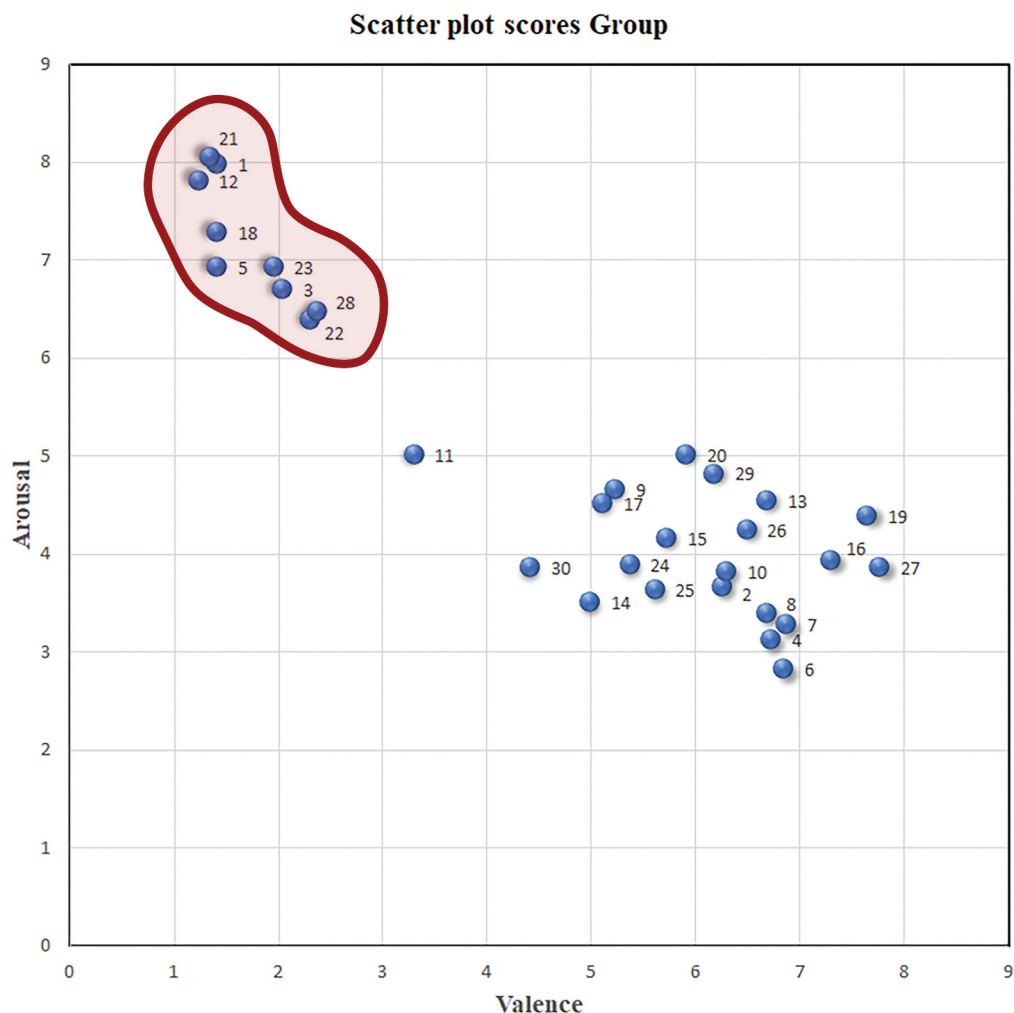
**Table 2. (Continued)**

Image	Valence						Arousal							
	Mean	SD	min	max	range	Norm	Dif	Mean	SD	min	max	range	Norm	Dif
25	5.62	1.79	1	9	8	5.35	-0.27	3.62	1.77	1	8	7	3.39	-0.23
26	6.50	2.13	1	9	8	5.53	-0.97	4.23	2.39	1	9	8	4.83	0.60
27	7.77	1.21	5	9	4	7.22	-0.55	3.85	2.11	1	9	8	3.63	-0.22
28	2.38**	1.27	1	5	4	2.96	0.58	6.46**	1.93	2	9	7	6.82	0.36
29	6.19	2.27	1	9	8	5.48	-0.71	4.81	2.39	1	9	8	5.09	0.28
30	4.42	1.50	1	9	8	5.98	1.56*	3.85	1.79	1	7	6	4.84	0.99

\* Highest differences between group and reference scores.

\*\* Highest differences between Arousal and Valence (distress), corresponding to the nine images in the left upper quadrant in the circumplex model (Figures 1 and 5).

**Figure 5. Scatter plot of mean scores in Valence and Arousal. Encircled are the nine images in the distress area, according to the circumplex model (Figure 1).**



that the emotional response from watching the images are diverse and/or that similar emotional responses are reported differently on the SAM test due to individual variables.

There is a strong correlation between the group mean scores and the IAPS normative values both in the *Valence* dimension ( $r(28) = .93, p > .001$ ) and in *Arousal* ( $r(28) = .92, p > .001$ ).

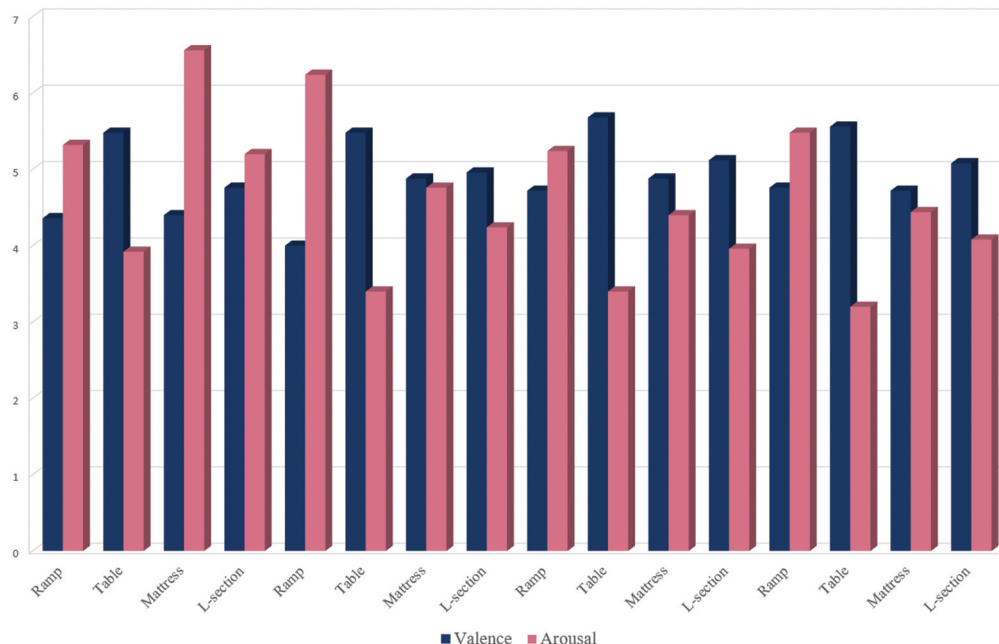
## 5.2. Gait test

### 5.2.1. Gait task type and perceived distress

To evaluate the gait protocol, we explored the differences in perceived stress across gait tasks (Table 3 and Figure 6). We expected that shapes with turns *Table* and *L* would be more demanding in terms of manoeuvrability and thus generate more stress than straightforward paths (*Ramp* and *Mattress*). We also expected that uneven and soft surfaces (*L* and *Mattress* respectively) would elicit more distress on participants than firm and smooth surfaces, and finally that slopes (*Ramp*) were more demanding than flat surfaces (*Table*, *Mattress* and *L*).

Table 4 presents a summary of descriptive statistics of scores for each gait task type. we can observe that the gait task with highest scores on *Arousal* and lower in *Valence* is *Ramp*.

**Figure 6. Valence and Arousal by gait task.**



To assess the effect of the different gait tasks on reported stress, a one-way ANOVA was performed. The analyses revealed that there is a statistically significant difference in both *Valence* ( $F(3, 396) = [6.952], p < .001$ ) and *Arousal* ( $F(3, 396) = [19.428], p < .001$ ) between at least two different gait tasks, so we have to reject the null hypothesis and accept the alternative hypothesis that gait task type affects the emotional response measured by SAM in both dimensions *Valence* and *Arousal* (Table 5).

To compare the results between each task type, we carried out a post hoc Bonferroni multiple comparison test with the results summarised in Table 5. The comparison test found that the mean value of *Valence* is significantly higher in *Table* compared to *Ramp* ( $p < .001$ , 95% CI = [.4270, 1.7530]) and compared to *Mattress* ( $p = .006$ , 95% CI = [.1670, 1.4930]), but not compared to *L* ( $p = .139$ ). There are no statistically significant differences between *Ramp* and *Mattress* ( $p = 1.00$ ) and *Ramp* and *L* ( $p = .229$ ).

*Arousal* is significantly higher in *Ramp* with respect to *Table* ( $p < .001$ , 95% CI = [-1.7530, -.4270]) and with respect to *L* ( $p = .001$ , 95% CI = [.3187, -1.8813]). There is no statistically significant difference in *Arousal* between *Ramp* and *Mattress* ( $p = .716$ ). *Arousal* scores are significantly lower in *Table* with respect to the other tasks: *Ramp* ( $p < .001$ , 95% CI = [-2.9013, -1.3387]), *Mattress* ( $p < .001$ , 95% CI = [-2.4413, -.8787]) and *L* ( $p = .004$ , 95% CI = [-1.8013, -.2387]).

### 5.2.2. Contextual stressors and perceived stress

To evaluate the effect of contextual stressors *blindfolded* and *braked wheel* we explored the differences of perceived stress across conditions. We expected that walking blindfolded would elicit more stress than walking with full vision and that handling the rollator with a braked wheel would increase stress as well. The descriptive data of the scores under the different conditions are presented in Table 6.

A one-way ANOVA was performed to compare the effect of the vision condition on reported stress walking the *Ramp* ( $n = 100$ ). The analyses reveal that there is a statistically significant difference in *Arousal* when walking blindfolded ( $F(1, 98) = [17.097], p < .001$ ), but not in *Valence* ( $p = .111$ ).

**Table 3. Descriptive statistics of the SAM scores for each gait task and circuit**

Circuit	Task	N	Valence					Arousal				
			Mean	SD	min	max	range	Mean	SD	min	max	range
C1	Ramp*	25	4.36	1.65	1	7	6	5.32	1.99	1	9	8
	Table	25	5.48	1.47	3	8	5	3.92	1.67	2	8	6
	Mattress*	25	4.40	2.23	1	9	8	6.56	1.58	3	9	6
C2	L	25	4.76	1.9	1	9	8	5.20	1.79	2	9	7
	Ramp*	25	4.00	1.92	1	7	6	6.24	1.75	2	9	7
	Table	25	5.48	1.58	3	9	6	3.4	1.62	1	6	5
C3	Mattress	25	4.88	1.86	1	9	8	4.76	2.34	1	9	8
	L	25	4.96	1.48	2	7	5	4.24	1.99	1	8	7
	Ramp	25	4.72	1.73	1	7	6	5.24	2.27	1	9	8
C4	Table	25	5.68	1.64	1	9	8	3.40	2.24	1	8	7
	Mattress	25	4.88	1.68	1	7	6	4.40	2.24	1	9	8
	L	25	5.12	1.84	1	9	8	3.96	2.05	1	8	7
C4	Ramp	25	4.76	2.06	1	9	8	5.48	2.02	1	9	8
	Table	25	5.56	1.44	3	9	6	3.20	1.90	1	7	6
	Mattress	25	4.72	1.76	1	7	6	4.44	2.14	1	9	8
L	25	5.08	1.49	1	7	6	4.08	2.17	1	9	8	

\*Gait: Task with highest scores in Arousal and lowest in Valence

**Table 4. Descriptive statistics of the SAM scores for gait task type**

	N	Valence					Arousal				
		Mean	SD	min	max	range	Mean	SD	min	max	range
Ramp	100	4.46	1.88	1	9	8	5.54	2.09	1	9	8
Table	100	5.55	1.55	1	9	8	3.42	1.84	1	8	7
Mattress	100	4.72	1.91	1	9	8	5.08	2.28	1	9	8
L	100	4.98	1.71	1	9	8	4.44	2.10	1	9	8

**Table 5. Summary of SAM descriptive statistics for Task Type, the ANOVA and post hoc multiple comparisons (Bonferroni)**

SAM	Tasks				ANOVA			Post -hoc Bonferroni test p-value				
	Ramp	Table	Mattress	L	F	p-value	R/T	R/M	R/L	T/M	T/L	M/L
Valence	M 4.46	5.55	4.72	4.98	6.952	<.001*	<.001*	1.00	0.23	<.001*	0.14	1.00
	SD 1.88	1.55	1.91	1.71								
Arousal	M 5.54	3.42	5.08	4.44	19.428	<.001*	<.001*	0.72	<.001*	<.001*	.004*	0.18
	SD 2.09	1.84	2.28	2.10								

\*Significant level  $p < .01$

**Table 6. Summary of results for blindfolded (only in Ramp) and braked wheel conditions**

SAM		Blindfolded		Braked	
		Yes	No	Yes	No
		(n = 50)	(n = 50)	(n = 200)	(n = 200)
Valence	M	4.16	4.76	4.79	5.07
	SD	1.97	1.76	1.86	1.74
Arousal	M	6.34	4.74	4.80	4.44
	SD	1.72	2.13	2.27	2.17

A one-way ANOVA was performed to compare the effect of a braked wheel on reported stress in the four Gait Tasks. The analyses reveal that there is no statistically significant difference for braked/not braked occurrences neither in *Arousal* nor in *Valence*.

## 6. Discussion

This study aimed to assess a stress generating test to investigate the distress response while walking with a rollator under different levels of demand. The outcome variable of perceived stress was measured by the SAM questionnaire to test the potential of the designed gait tasks as a stress elicitation test and to evaluate the IAPS based test to establish the stress response baseline of participants.

### 6.1. Self-Assessment Manikin

According to our results, the paper and pencil version of the two dimensions SAM questionnaire is feasible and easy to understand and to self-administer, quick to answer as an instant report and does not disrupt the flow of the trial either in the image test or in the gait test. In the gait test, the questionnaire was sensitive to the task type and to the stressors. Therefore, we consider the SAM questionnaire a valid instrument to measure the subjective response of stress in this context and suitable measurement to be used as a gold truth for psychophysiological and behavioural data in automatic stress estimation (Can et al., 2019; Lutscher, 2016).

### 6.2. IAPS Test

The strong correlation between the gathered scores and the normative values provided by the IAPS shows that the standardized test is a good predictor of a participant's perceived stress response. Therefore, we can validate the selection of images as a feasible and sensitive test to elicit different levels of stress and conclude that the selected images are a good test to establish the participant's stress response baseline and also to calibrate other data such as psychophysiological signals. Due to the individual variability in emotional response and in reporting the subjective experience (Can et al., 2019) this test can consequently help to customize automatic stress detection into personalized thresholds.

### 6.3. Gait test

Results show that perceived stress varies across gait tasks and stressors. Walking on a slope (*Ramp*) or on non-firm surfaces (*Mattress*) appears to cause more stress in participants. On the other hand, the shape of the trajectory does not seem to add more demands to the activity as expected, and turning trajectories in *Table* and *L* do not elicit higher scores in *Arousal* different from straightforward trajectories like *Ramp* and *Mattress*.

The effect of the stressor *braked wheel* on the emotional response is not conclusive. One tentative explanation is that participants with no mobility impairment could easily compensate the raised areas by lowering the strength exerted upon the rollator and even by slightly lifting the braked wheel. This would not be expected in people with impairment mobility. Further analyses of the video recorded gait will offer a more complete view of this compensation. In addition, the

repetition of the circuit and tasks allows the exploration of other relevant factors that affect performance such as learning and fatigue.

## 7. Conclusions and further work

In relation to the research questions, the assisted walk performance-oriented protocol and trial results showed that the SAM questionnaire was a feasible and useful instrument to measure perceived stress in the context of assisted gait. The developed gait circuit was shown to have the potential to train automatic stress detection systems, in particular, the uneven or sloping surfaces increasing perceived stress.

The development of effective assistive gait technology such as smart rollators would benefit from integrating the user's psychological comfort with clinical knowledge and movement data. To do so, more research into psychological response during walking with a rollator is needed to identify the factors that increases the user discomfort and how in turn this discomfort affects gait. Stress generating tasks are a useful setting to systematically investigate the dynamics of psychological states during gait under controlled conditions.

This preliminary study faces some limitations. First, the stress generating test developed is designed only for healthy participants with no mobility impairment and not used to gait aids. The situation recreates and augments different stress-inducing conditions in gait to provoke in healthy participants a sense of loss of control and uneasiness during assisted walk. We assume as a working hypothesis that the participants' responses to gait-related events are reasonably close to the experience experimented by actual users of rollators and consider that the similarities justify the use this setting to train automatic stress detections systems in initial phases. And second, the results are drawn from a small number of participants and further testing is required for the protocol validation and for the study of individual factors such as gender and age.

The present study belongs to a broader research project on the development of a robotized rollator. The rollator includes a shared control paradigm for inpatient rehabilitation that relies on performance and contextual data to adapt the assistance to the user needs (Fernandez-Carmona et al., 2022). The proposed protocol is meant to provide information on stress levels to adapt the shared control system, in order to provide a more efficient and comfortable assisted navigation. Further steps in the ongoing research will address (i) the extension of the self-reported data base with healthy participants, (ii) the behavioral analyses of gait response to stress from video-recorded data (iii) the triangulation of self-reported data with psychophysiological data from wearable sensors and with navigation and gait data from on board sensors to cross-validate results. Preliminary results from a pilot study can be seen in (Díaz-Boladeras et al., 2021).

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### Author details

Marta Díaz-Boladeras<sup>1</sup>  
E-mail: [marta.diaz@upc.edu](mailto:marta.diaz@upc.edu)  
ORCID ID: <http://orcid.org/0000-0001-8215-0499>  
Xavier Llanas<sup>1</sup>  
ORCID ID: <http://orcid.org/0000-0002-7149-7996>  
Manuel Fernandez-Carmona<sup>2</sup>  
ORCID ID: <http://orcid.org/0000-0002-0512-8594>  
Andreu Catalá<sup>1</sup>  
ORCID ID: <http://orcid.org/0000-0001-8775-1955>  
Cristina Urdiales<sup>2</sup>  
ORCID ID: <http://orcid.org/0000-0002-9251-6447>  
Marta Musté<sup>1</sup>  
ORCID ID: <http://orcid.org/0000-0002-6965-2918>  
Elsa Pérez<sup>1</sup>

ORCID ID: <http://orcid.org/0000-0001-7221-054X>

Àlex Barco<sup>1</sup>

ORCID ID: <http://orcid.org/0000-0002-7224-2186>

<sup>1</sup> Technical Research Centre for Dependency Care and Autonomous Living (CETpD), Universitat Politècnica de Catalunya BarcelonaTech (Upc), vilanova I la Geltrú, Spain.

<sup>2</sup> Instituto Universitario de Investigación en Telecomunicación (TELMA), University of Málaga, Málaga, Spain.

### Disclosure statement

No potential conflict of interest was reported by the author(s).

### Data availability statement

The data that support the findings of this study are available from the corresponding author, [M D-B], upon reasonable request <https://dataverse.csuc.cat/privateurl.xhtml?token=3a3c879e-f9f7-480a-a7e3-a85f646149ea>.

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