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unexpected perturbations while walking in virtual reality environment V.1

PLOS One

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Uri Rosenblum

ABSTRACT

Walking perturbations are a well-established tool to study human performance of balance tasks. We aimed to characterize walking and balance reactions in adults with and without neurological disease. Participants walked on self-paced treadmill while being exposed to unexpected surface displacement Perturbations. these were introduced at different phases of the gait cycle, on both legs and in anterior-posterior or medio-lateral directions, in random order.

Two types of perturbations were implemented: (1) medio-lateral platform perturbations were achieved by displacing the moving platform 15 cm, to the left or to the right, over 0.92 seconds. The platform held its new position for 30 seconds and then returned gradually to its original position over 3 seconds; (2) anterior-posterior treadmill belt perturbations were achieved by reducing the speed of one of the treadmill belts by 1.2 m/s with a deceleration of 5 m/s^2.

Relevant gait phase, gait parameters of step length and width as well as walking speed were detected and calculated from force plate and markers data in the sagittal plane.

Force plate data was filtered using a low-pass filter with cutoff frequency of 5Hz and a force threshold of 25N is used; no filters were applied to the marker data.

The protocol has two steps: (1) self-pace learning and (2) walking with unexpected surface displacement perturbations.

EXTERNAL LINK

https://doi.org/10.1371/journal.pone.0233510

THIS PROTOCOL ACCOMPANIES THE FOLLOWING PUBLICATION

Novel methodology for assessing total recovery time in response to unexpected perturbations while walking
Uri Rosenblum, Lotem Kribus-Shmiel, Gabi Zeilig, Yotam Bahat, Shani Kimel-Naor, Itshak Melzer, Meir Plotnik
bioRxiv 846923; doi: https://doi.org/10.1101/846923

GUIDELINES

For any questions you are welcome to contact the principal investigator of the Center of Advanced Technologies in Rehabilitation Dr. Meir Plotnik at: Meir.Plotnik@sheba.health.gov.il.

MATERIALS TEXT

1. Apparatus

Virtual reality-based paradigm using the Computer Assisted Rehabilitation Environment (CAREN) High-End (Motek-Medical,

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the Netherlands; see Fig 1), a motion base platform with an imbedded treadmill, surrounded by a 360° dome shaped screen, enabling optimal immersion in a largescale VR setting. During walking trials, participants (in a safety harness) were presented with simulated ecological surroundings (e.g., urban public park).Underneath the belts there are two parallel force plates (Zemic load cells; The Netherlands), one under each belt. Each force plate has 6 sensors. Two sensors for the X axis (medio-lateral; ML), three sensors for the Y axis (vertical) and one sensors for the Z axis (anterior-posterior; AP). Force measurement precision is 0.5N (~51gr) and the reliable range of measurement is 0-500kg.

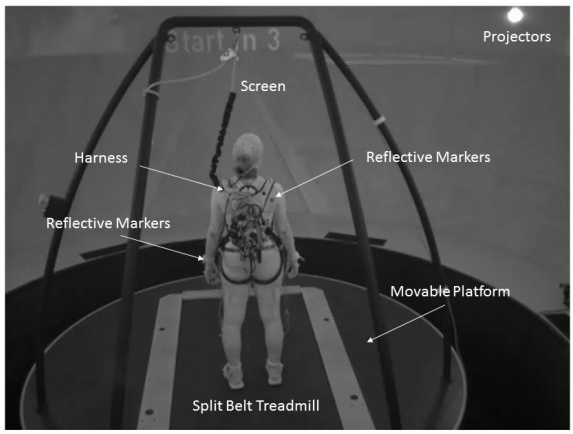

Fig.1. Experimental setup. Participants walked on a treadmill in self-paced mode. The treadmill is embedded in a moveable platform with six degrees of freedom (three translations and three rotations). They were exposed to unexpected platform (medio-lateral) or treadmill (anterior-posterior) perturbations in a virtual reality environment. Vicon, motion capture cameras, were used to calculate walking parameters of step length and step width based on marker data from the feet. A small backpack was used to carry a wireless amplifier connected to biosensors (e.g., electroencephalography, electromyography), data from which are not reported here.

2. Motion Capture System

Vicon (Vicon Motion Systems, Oxford, UK) motion capture system with 18 cameras is used with a set of 41 body markers. sampling rate was set to 120Hz. the system's spatial accuracy is 0.11 cm).

Recruit Participants

1 **Iclusion Criteria**

Participants can be included in the study if they are:

* Usually healthy
* age 18-90

Exclusion criteria

Participants cannot be included in the study if they present the following conditions:

* obesity (body mass index (kg/m^2)> 30 [1])
* orthopedic condition affecting gait and balance (e.g., total knee replacement, total hip replacement, ankle sprain, limb fracture, etc.).
* cognitive or psychiatric conditions that could jeopardize the participant's ability to participate in the study (Mini-Mental State Exam score < 24 [2]).
* heart condition, such as non-stable ischemic heart disease or moderate to severe congestive heart failure.
* severe chronic obstructive pulmonary disease.
* neurological disease associated with balance disorders (e.g., multiple sclerosis, myelopathy, etc.)

Collect demographic information from participants

2 **Participant Code**

acronym of first and last name + 3 last digits of ID (e.g. UR193)

3 **Date**

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4 **Sex**
Sex of participant.
If male, code as 1.
If female, code as 0.

Missing data should be marked with 555

5 **Date of birth**

Missing data should be marked with 555

6 **Hight**
hight in meters, two decimal places precision

Missing data should be marked with 555

7 **Leg length**
Length of the right limb from the greater trochanter to the floor in cm.

Missing data should be marked with 555

8 **Weight**
Weight in Kg.

Missing data should be marked with 555

9 **BMI**
Body mass index calculated using the formula kg/m^2

Missing data should be marked with 555

10 **Years of Education**
record the number of years of Education for the participant

Missing data should be marked with 555

11 **Falls in the last year**
Did the participant fall in the last year?
If yes, code as 1
if no, code as 0

Missing data should be marked with 555

11.1 **If fell, how many times in the last year?**
Record number of falls in the last year

If not relevant leave empty.

Cognitive tests

12 For older adults perform the Mini Mental State Examination

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Mini Mental State Examination

	התמצאות: (שאל/י את השאלות הבאות)	1	0
.1	מה התאריך היום?		
.2	באיזה שנה אנחנו?		
.3	באיזה חודש אנחנו?		
.4	איזה יום היום?		
.5	באיזו עונה אנחנו?		
.6	מה שמו של בית החולים הזה?		
.7	באיזו קומה אנחנו?		
.8	באיזו עיר אנחנו?		
9	באיזה אזור בארץ אנחנו?		
.10	באיזו ארץ אנחנו?		

זיכרון מיידי: שאל/י את החולה אם אפשר לבדוק לה/לו את הזיכרון. תגיד כדור, דגל, עץ, באופן ברור ואיטי, בערך שנייה לכל מילה. אחר כך תבקש/י מהחולה לחזור על המילים. סמן/י כל תשובה נכונה בריבוע המתאים. התזרה הראשונה קובעת את התוצאה . אם החולה אינו/ה חוזר/ת על שלושת המילים. באופן נכון, תמשיך/י להגיד אותם עד לשישה ניסיונות ועד שהוא/היא מצליח/ה לחזור עליהן.

		1	0
.11	כדור		
.12	דגל		
.13	עץ		

	ריכוז וחישוב: בקש/י מהחולה לאיית את המילה "שולחן" לאחור.	1	0
.14	ן		
.15	ח		
.16	ל		
.17	ו		
.18	ש		

	זיכרון: בקש/י מהחולה להיזכר בשלושת המילים שקודם ביקשת ממנו/ה לזכור. סמן/י כל תשובה נכונה בריבוע המתאים.	1	0
.19	כדור		
.20	דגל		
.21	עץ		

	שיום (קריאה בשם): הראה/י לחולה שעון יד ובקש/י ממנו לתגיד מה זה . חזור/י על ההוראה כאשר את/ה מראה לו/ה עפרון.	1	0
.22	שעון		
.23	עפרון		

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חזרה: בקש/י מהחולה לחזור על המשפט:	1	0
24. לא כל הנוצץ זהב הוא.		
ברר/י איזו יד היא הדומיננטית אצל החולה. תן/י לחולה דף נייר ריק ואמור/י:	1	0
25. קח את הנייר ביד ימין/שמאל.		
26. קפל אותו ל- 2.		
27. שים אותו על הרצפה.		
28. קריאה: הראה/י לחולה כרטיס בו כתוב: "עצוס עיניים" כך שיוכל לראות בבירור. בקש/י ממנו/ה לקרוא אותו ולבצע את ההוראה. סמן/י את הריבוע רק אם החולה אכן עוצם את עיניו.	1	0
29. כתיבה: תן לחולה דף נייר ובקש ממנו /ה לכתוב משפט. הכתיבה צריכה להיות ספונטנית. אם המשפט הגיוני, כולל נושא ופועל, סמן את הריבוע. אין לייחס חשיבות לדקדוק וניקוד.	1	0
30. העתקה: הראה לחולה ציור של 2 מחומשים חופפים. בקש/י ממנו/ה לצייר את הצורה בדף. אם עשר הזוויות קיימות ושתי הצורות חופפות סמן/י את הריבוע, אין להתייחס לרעד.	1	0

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Fig. 2. Mini Mental State Examination in Hebrew

13 **Colors Trails Test:** the test consists of two parts. In part 1 the participant is asked to connect the numbers 1-25 with lines as fast as they can. In part 2 the objective is the same but every number appears twice, in yellow and pink colors. The participant has to alternate between the colors as they connect the numbers from 1-25. Participants performed part 1 and part 2.

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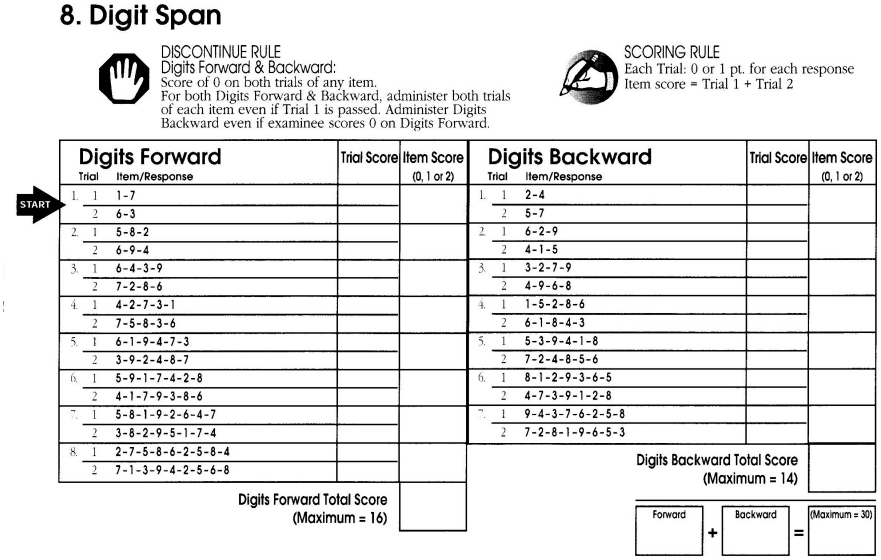
14 **Digit Span Test:** the participant is required to repeat sequences of numbers read to them by the examiner. First they repeat them forward (from start to end) and then they have to repeat them backwards (from end to start).



8. Digit Span

DISCONTINUE RULE
Digits Forward & Backward:
Score of 0 on both trials of any item.
For both Digits Forward & Backward, administer both trials of each item even if Trial 1 is passed. Administer Digits Backward even if examinee scores 0 on Digits Forward.

SCORING RULE
Each Trial: 0 or 1 pt. for each response
Item score = Trial 1 + Trial 2

Digits Forward Trial	Item/Response	Trial Score	Item Score (0, 1 or 2)
START 1. 1	1-7		
2	6-3		
2. 1	5-8-2		
2	6-9-4		
3. 1	6-4-3-9		
2	7-2-8-6		
4. 1	4-2-7-3-1		
2	7-5-8-3-6		
5. 1	6-1-9-4-7-3		
2	3-9-2-4-8-7		
6. 1	5-9-1-7-4-2-8		
2	4-1-7-9-3-8-6		
7. 1	5-8-1-9-2-6-4-7		
2	3-8-2-9-5-1-7-4		
8. 1	2-7-5-8-6-2-5-8-4		
2	7-1-3-9-4-2-5-6-8		
Digits Forward Total Score (Maximum = 16)			

Digits Backward Trial	Item/Response	Trial Score	Item Score (0, 1 or 2)
1. 1	2-4		
2	5-7		
2. 1	6-2-9		
2	4-1-5		
3. 1	3-2-7-9		
2	4-9-6-8		
4. 1	1-5-2-8-6		
2	6-1-8-4-3		
5. 1	5-3-9-4-1-8		
2	7-2-4-8-5-6		
6. 1	8-1-2-9-3-6-5		
2	4-7-3-9-1-2-8		
7. 1	9-4-3-7-6-2-5-8		
2	7-2-8-1-9-6-5-3		
Digits Backward Total Score (Maximum = 14)			

Forward + Backward = (Maximum = 30)

15 NeuroTrax (NeuroTrax Corporation, NY, USA) computerized battery of cognitive tests which assesses different cognitive domains related to motor and postural control.

Cognitive dual task

16 **Teach and train participant on cognitive task**

Paced auditory sirial addition task of 15 numbers that are read every **00:00:02** .

the participants are asked to add the numbers quitly in their head. at the end of the reading they have to give the sum of the numbers that were read to them. In the table below are the number series for practice and baseline measure.

List 1	List D'	List C'	List B'	List A'	
8	9	1	4	7	1
5	4	4	6	9	2
4	4	7	4	6	3
5	4	5	9	6	4
3	6	3	7	8	5
5	5	2	3	4	6
5	2	4	1	3	7
9	6	5	1	4	8
7	5	2	5	8	9
2	5	6	6	5	10
9	7	4	6	8	11
2	5	6	2	4	12
2	6	3	7	3	13
7	8	1	7	9	14
8	9	8	5	9	15
81	85	61	73	93	Sum
					SumRep

Lists A-D are for training.List 1 serves as the baseline for the cognitive task. cognitive test score are out of 100% (No Errors) and are calculated using the following formula:

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Sum_{Rep} = Reported Sum

16.1 **Record score for List 1**
Cognitive score List 1 = 100-((|81-X|)/5.4)*6.66

Clinical walking tests

17 **Time Up and Go Test:** The test starts with the participant seated in a chairs with arm rests. Than the participant is asked to get up and walk 3 meters to a mark on the floor, turn around and go back to sit in the chair, in their comfortable speed. The test is ended when the participant is seated in the chair. The test is times from the moment the participants starts to get up to the time they seat back in the chair at the end. The test was Performed twice in comfortable walking speed.

18 **10 Meter Walking Test:** The participant is asked to walk in their comfortable walking speed and the result of the test is the time to complete 10 meters in the middle of a 30-meter-long corridor. The test was repeated 4 times.

18.1 **10 Meter Walking Test with a concurrent cognitive task:** Participants performed the 10 meter walk test with a concurrent cognitive task of subtracting 7 from a random three digits number. The test was repeated 4 times.

19 **2 Minute Walking Test: t**he participant has to cover the greatest distance they can in two minutes of walking back and forth in a 30-meter-long corridor. The result of the test in the distance covered during the trial.
Step 19 includes a Step case.
Age group
Age group

step case

Age group

The participant is a young adult

20 **High Level Mobility Assessment Tool (HiMAT):** a high level functional test that includes tasks such as fast walking, running, climbing stairs and jumping.
HiMAT.pdf

Main Experiment

21 **Prepare participant for the experiment**
* Fit participant with a harness
* Explain to the participant that they are tied and cannot fall.
* Callibrate vicon system to the participant's range of motion.

22 **Stage I: Self-paced walking – learning and acclimation**
The trials starts with acclimation sessions during which participants are introduced to the self-paced walking paradigm. Participants are asked to maintain their comfortable walking speed for one minute, and then to dynamically

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modify their gait speed, including accelerating, decelerating, coming to a full stop, and resuming their comfortable walking speed. This is repeated until they reef confident and perform the transition from standing to comfortable walking speed smoothly.

Self-paced walking mode
The treadmill was operated in self-paced mode, in which the motor is operated as a function of the instantaneous position and speed of the participant, which are sampled using a motion capture system (see more details in [3]).

23 **Stage II: Introducing physical perturbations during walking**
The protocol consisted of walking trials in two different scenes (park and a no hands hanging bridge over a deep canyon). Every scene was used in 4 walking trials of single task and dual task conditions (see Fig. 3 for more details).

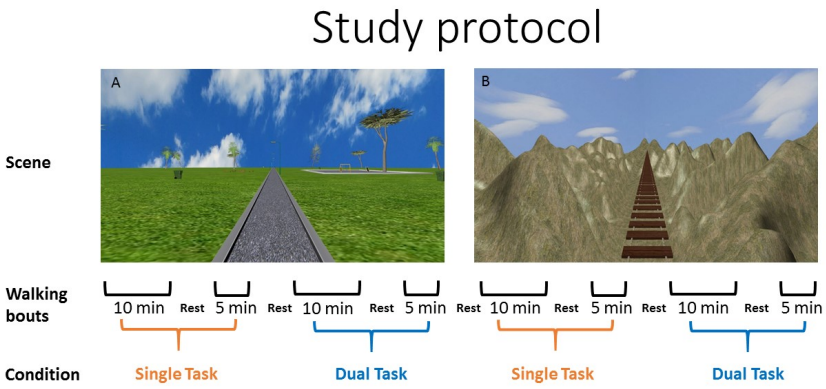

Fig. 3. Study protocol. The protocol consisted of walking trials in two different scenes, park (A) and a no hands hanging bridge (B). Every scene was used in 4 walking trials of single task and dual task conditions in walking bouts of ten and 5 minutes with rest between walking trails. Participants, performed eight walking trails, with the exception of one young, and 5 older participants that asked to stop. The order of the scenes and the conditions was randomized across participants.

Once the participant reached steady state walking velocity, one of several types of unexpected perturbations was randomly presented (see Fig.4) in two trials conditions: (a) the single task condition, in which no additional cognitive load was introduced; (b) the dual task condition, in which participants were asked to perform concurrent arithmetic calculations they learned in step 16, higher cognitive load. Participants were instructed to react naturally to the perturbations, to prevent themselves from falling.
A total of 18 possible surface perturbations were used in random order to reduce learning effects anticipatory reactions from trial to trial.
At least 30 seconds of baseline walking were implemented before and after every perturbation to allow full recovery of the kinematic gait parameters.

Physical perturbations
Perturbation types were classified according to the following criteria: (1) perturbation direction –medio-lateral (i.e. right or left platform displacement) or anterior-posterior (i.e. deceleration of one of the treadmill belts); (2) gait cycle phase – immediately after initial contact, mid-stance, or towards toe off, as detected in real time from foot markers and force plates data; and (3) foot of reference (right or left foot that were detected in the relevant gait phase). An example for perturbation type by criteria would be: (1) platform left in (2) initial contact (3) right =a displacement of the platform to the left was executed when initial contact phase was detected for the right foot. Medio-lateral platform perturbations were achieved by displacing the moving platform 15 cm, to the left or to the right, over 0.92 seconds (perturbation level 12, see Fig. 4). The platform held its new position for 30 seconds, to allow full recovery of the gait parameters (i.e., step length

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and step width), and then returned gradually to its original position over 3 seconds; (2) anterior-posterior treadmill belt perturbations were achieved by reducing the speed of one of the treadmill belts by 1.2 m/s with a deceleration of 5 m/s^2(perturbation level 12, see Fig. 4). To enable anterior-posterior perturbations, the treadmill speed was fixed to the measured average self-paced walking speed 5 seconds prior to perturbation onset. The perturbation was presented when the relevant gait phase was detected, and 3 seconds later the treadmill was once again set to self-paced mode (see perturbation profiles, Fig 4).
Relevant gait phase was detected using force plate data and toe marker data in the sagittal plane. Force plate data was filtered using a low-pass filter with cutoff frequency of 5Hz and a force threshold of 25N is used; no filters were applied to the marker data. Initial contact was detected when the vertical force from the foot in front (leading limb) exceeded a minimum for of 35N (minimum force was chosen to avoid force plate baseline noise); mid-stance was detected 200ms after initial contact; and toe off was detected when the vertical force from the force plate on the side of the trailing limb went under the minimum force. Once the relevant gait phase was detected the main system computer gave a command to the platform or the treadmill belt to execute the perturbation. Since there was a lag time between the detection of the relevant gait phase and perturbation execution, we re-evaluated the actual perturbation type post-hoc. Gait phases and leading limb were defined using the heel markers' position in the sagittal plane [4]. Initial contact and toe off were detected when the heel marker was at its maximal forward or backward position, respectively, with 0.025 seconds margins. Perturbation that was introduced beyond this margins was considered a mid-stance perturbation.
Perturbation magnitude and timing (see experimental procedure below) were controlled and modified by the VR system computer.

Fig2.jpg

Fig. 4. Perturbation profiles used in the platform (top) and treadmill (bottom) experiments.
Possible perturbation levels ranged from Level 1 to Level 20, participants in the study were subjected to perturbation magnitude Level 12. For platform perturbations, Level 12 is implemented by displacing the platform 15 cm to the right or left over 0.92 seconds. The levels were used to allow for participants who feared the high magnitude perturbations to participate (four out the 12 older adults). The levels were constructed so that the platform displacement is always 15 cm and the time to complete the distance was manipulated between 1.36 seconds (Level 1) to 0.6 seconds (Level 20); decrease of 0.04 seconds per level. For treadmill perturbations, Level 12, we used a deceleration of 5 m/s^2 and speed reduction of 1.2 m/s. For the different levels we used fixed deceleration of 5 m/s^2 and the reduction in speed was manipulated between 0.1 m/s (Level 1) to 2 m/s (Level 20); increase of 0.1 m/s per level. Prior to and immediately following the treadmill perturbation (periods between black and red vertical dashed lines, respectively), self-paced was switched off and the two belt speeds were fixed to the mean walking speed in the last 5 seconds; (see text for further details). SSV – steady state velocity

Capturing gait parameters

Gait speed was obtained from an encoder on the drive shaft of the treadmill motor. Spatial-temporal gait parameters (i.e., step times, step length, and step width) were obtained from a Vicon (Vicon Motion Systems, Oxford, UK) motion capture system. Gait cycle phases were detected using foot marker and force plate data.

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