Sense of Embodiment(SoE) Amplification for Paraplegic People by Lower Body Motion Generation in VR

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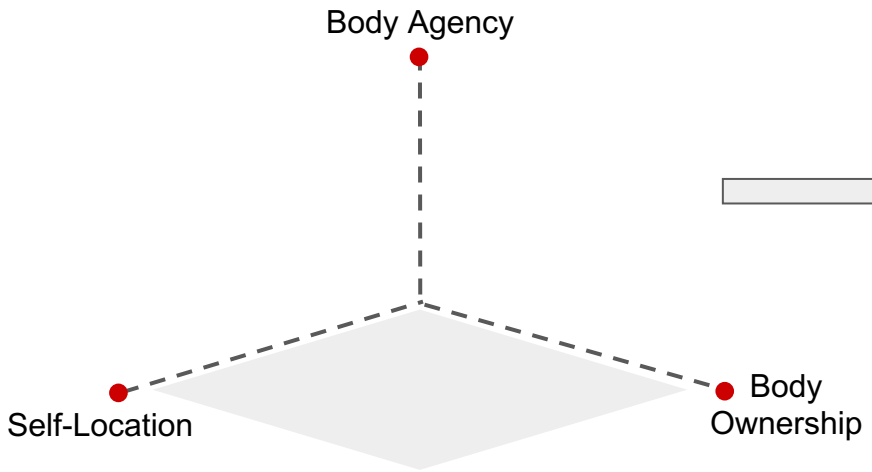
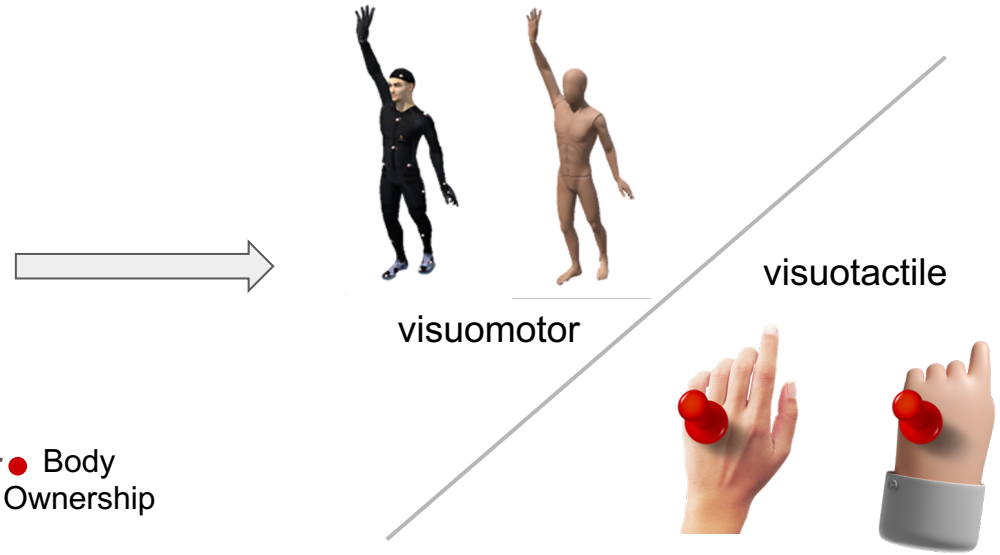
Importance of our topic: SoE

Sense of Embodiment (SoE)
= the sense of experiencing the avatar's body like one's own body





Importance of our topic: paraplegic patients for VE

[Limitation]

1) Hard to apply multi-sensory stimulation for inducing the SoE in virtual walking scenario
2) Most of 3D avatar animations and SoE-related researches target non-disabled users
3) Existing VR studies for paraplegic patients mainly deal with rehabilitation

New approach is needed for paraplegic individuals to improve the SoE in VE

Image Source: https://videohive.net/item/active-young-paraplegic-woman-using-virtual-reality-headset-sitting-on-wheelchair-indoors/30895707

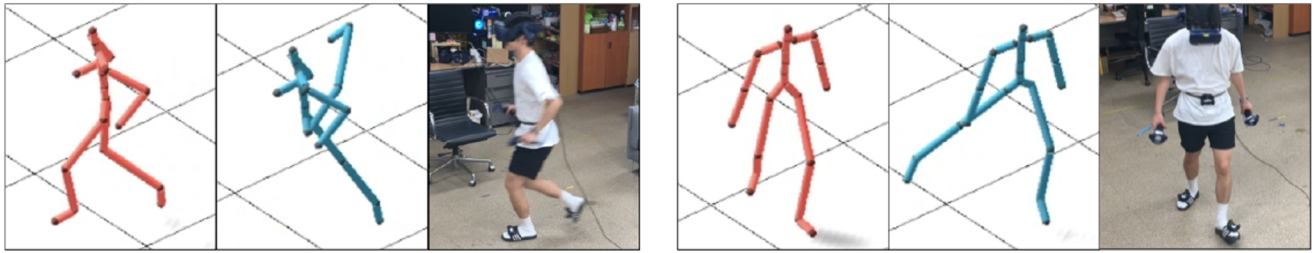
Importance of our topic: Technical perspective

source: https://www.computingnews.com/best-vr-games/

Increased use of Head Mounted Display

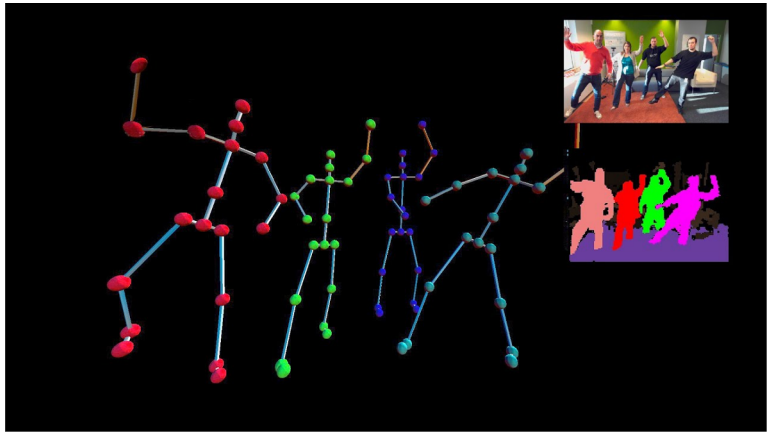
Increased contents for VR application

Importance of our topic: Technical perspective



Broken 6 point tracking

source: lobstr real-time lower-body pose prediction from sparse upper-body tracking signals(Eurographics)



Using depth-camera such as Kinect

source: DepthSence

Liable for Accumulative Error

Novelty of our work

Will automatic lower body generation will increase the SoE and satisfaction for paraplegic people in VR?

Comparison(related works): Tech



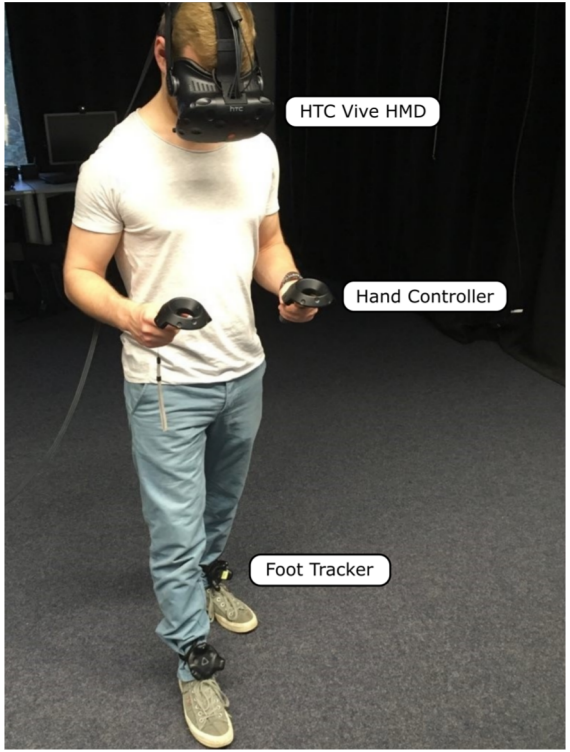

3D locomotion technique(real walking, walking in place, virtual steering) used has little influence on the user's sense of embodiment in VR when the user has a full control of his avatar movements

Our novelty

One step deeper from their virtual steering case to see whether automatic generation can enlarge SoE

Studying the Inter-Relation Between Locomotion Techniques and Embodiment in Virtual Reality

Comparison(related works): Tech



Address the question if the virtual self-representation of the user's feet changes the detection thresholds for translation gains

-> virtual environment is more important for manipulation detection than the visual self-representation of the user's feet

Our novelty

We automatize not only a simple virtual object but a motion of lower body as a whole

I Can See on My Feet While Walking: Sensitivity to Translation Gains with Visible Feet (IEEE VR)

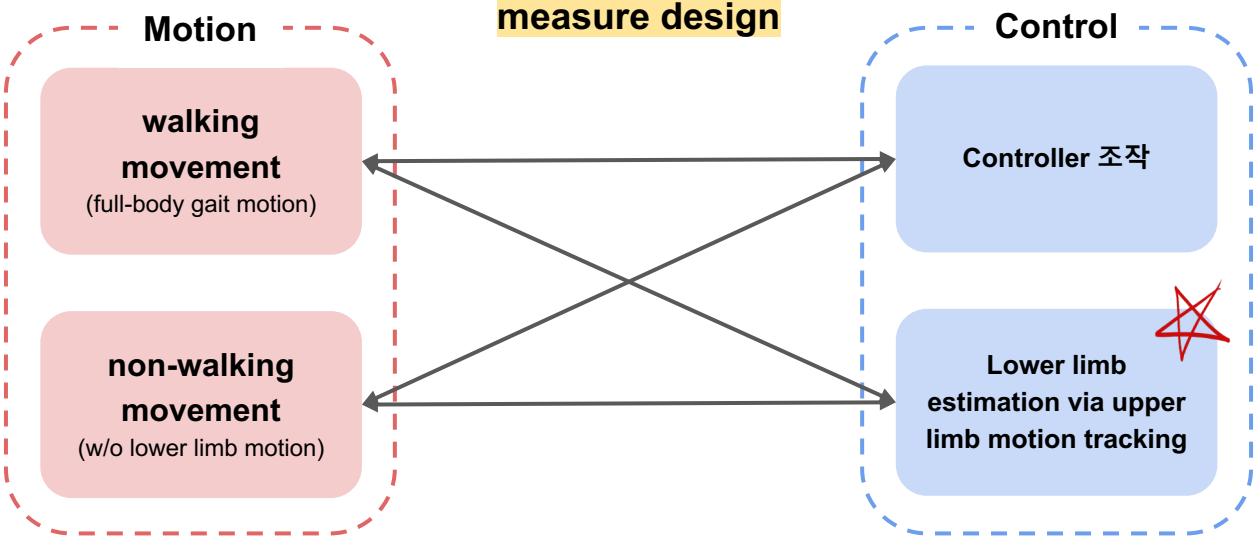
Comparison(related works): User Study

Key points	Reference	Summary
Suggest new method of using upper-body motion as an alternative to control a full-body movement	- Assimilation of virtual legs and perception of floor texture by complete paraplegic patients receiving artificial tactile feedback **(Shokur, 2016)** - The treatment of phantom limb pain using immersive virtual reality: Three case studies **(Murray, 2007)**	- remapped the lost lower-limb tactile sensation of paraplegic patients onto the forearm by using a haptic display - employed a contralateral limb motion of an amputated body part to estimate virtual body pose in a virtual environment. - amputees reported the sense of movement on their phantom limb while seeing their virtual full-body avatar move ⇒ **use of other body parts enables transmitting of bodily sensation on lost limb**
Induction of SoE in static user in VE	- First Person Perspective of Seated Participants Over a Walking Virtual Body Leads to Illusory Agency Over the Walking **(Kokkinara, 2016)** - Perception of Walking Self-body Avatar Enhances Virtual-walking Sensation **(Matsuda, 2020)** - Proprioceptive Stimulation Added to a Walking Self-Avatar Enhances the Illusory Perception of Walking in Static Participants **(Labbe, 2021)**	⇒ **Seated** users also could feel the **SoE** of walking avatar ⇒ **seated** participants still experience a **sense of walking** in virtual space ⇒ visual walking avatar was effective for the active walking sensations ⇒ The participants reported some degree of illusory perception that they were walking **with only visual feedback** ⇒ Albeit its perception is incomparable with multisensory condition, **immovable and insensate users still can feel the SoE**
Our chosen avatar = 1PP full body avatar	- Avatar and Sense of Embodiment: Studying the Relative Preference Between Appearance, Control and Point of View **(Fribourg et al., 2020)** - Characterizing first and third person viewpoints and their alternation for embodied interaction in virtual reality **(Debarba et al., 2017)**	⇒ PoV and control levels were consistently increased by users before appearance levels when it comes to enhancing the SoE ⇒ Task-dependent: In walking, PoV is significant → **1PP for self-location, IVBO** ⇒ Illusory ownership of a virtual body can be achieved in both first and third person perspectives under congruent visuo- motor-tactile condition ⟷ subjective body ownership and reaction to threat were generally **stronger** for **first person perspective** and alternating condition

User Study Method

Assumed a **moving scenario** & **full-body avatar** implementation to see the difference in VE and reality

2x2 within subject measure design



User Study Method

Research questions

1. Will SoE be improved more when the participants use upper-body tracking compared to the use of a controller?

2. Will SoE of paraplegic patients be improved when there is lower limb motion, despite the asynchronous condition?

3. Will upper-body tracking-based full-body gait motion condition induce the highest SoE?

+

To see whether the paraplegic patients would report positive sentiment toward full-body motion or not

Implementation

Case 1. Controller

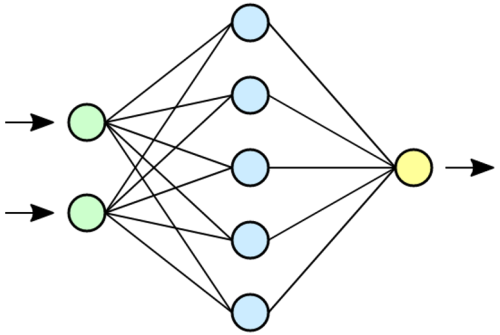
- Walking motion
- Non-Walking motion

Play Pre-recorded Animation
(Mixamo)

Implementation

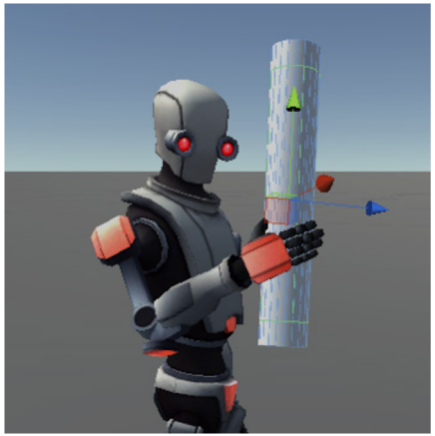
Case 2. Real-time Upper Body Tracking

- Walking motion



IK + Automatic
Lower Body Generation

- Non-Walking motion

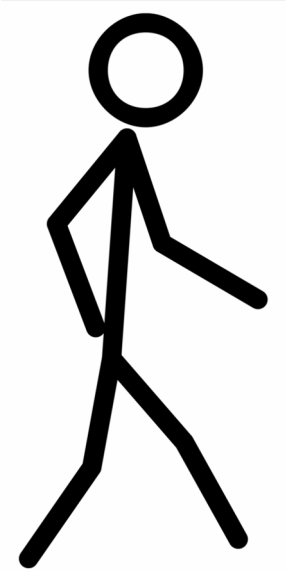


Unity VR IK

Implementation: Technical

If upper body movement is detected,
-> lower body generation initiated for both case

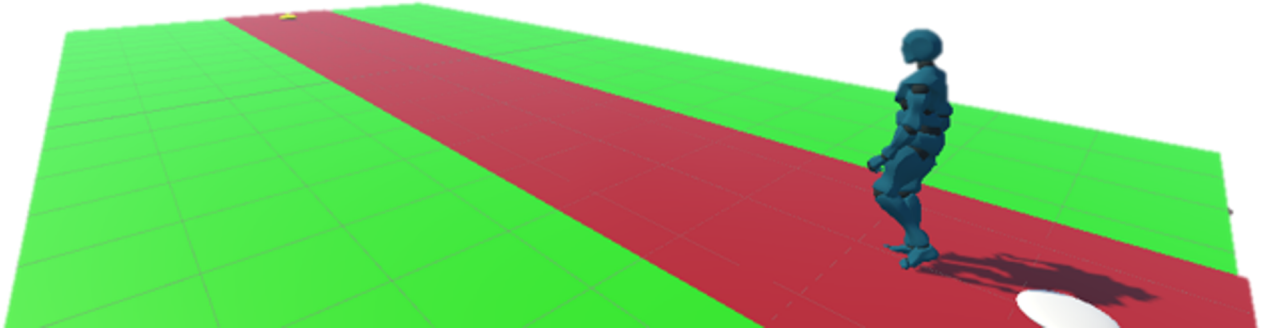
Upper Body -> Real-time IK
Lower body -> Low level animation play



Implementation: User Study

Task

- provide 100m virtual track surrounded by wall → block the confounding variables
- the participant is required to **go from start point(white) to end point(yellow)**
- **Simplify** the avatar representation to reduce the confounding variable
- According to previous work, PoV is **1PP**



Chowdhury, T. I., Ferdous, S. M. S., & Quarles, J. (2019). VR disability simulation reduces implicit bias towards persons with disabilities. *IEEE transactions on visualization and computer graphics*.

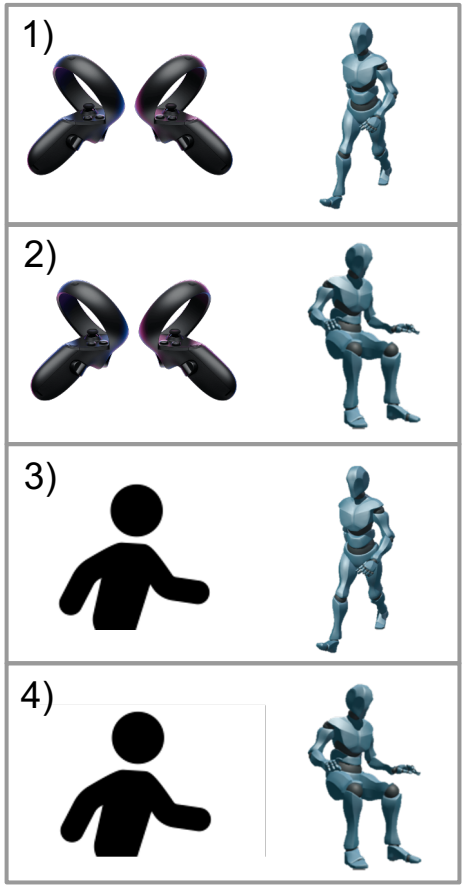
Implementation: User Study

Conditions

- **2x2 within subject design**
  1) [Cond.A] Controller + gait pose movement
  2) [Cond.B] Controller + seated pose movement
  3) [Cond.C] Upper motion + gait pose movement ← **our target condition**
  4) [Cond.D] Upper motion + seated pose movement

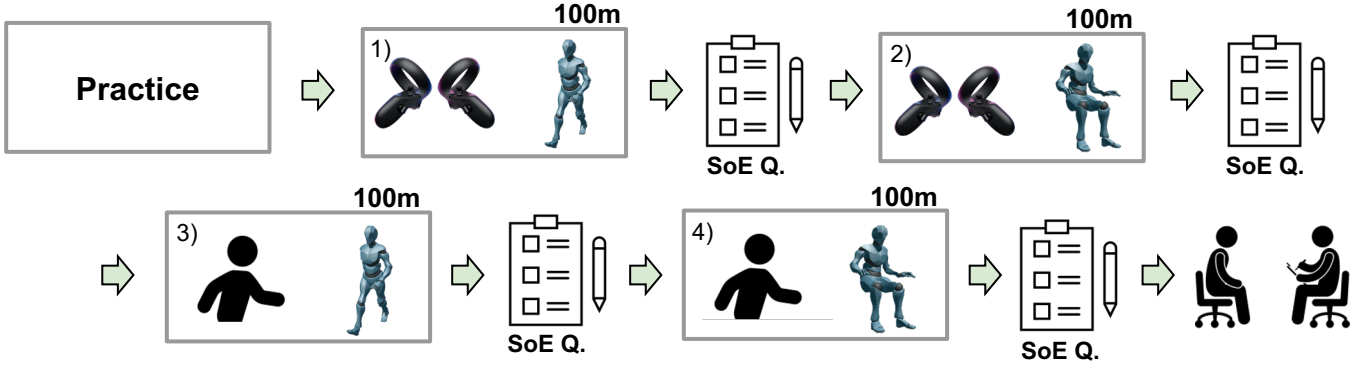
  ⇒ each condition has 200m long track
  ⇒ order is **RANDOMIZED** to be given
  ⇒ after each condition, <u>short SoE + preference questionnaire</u> will be given

- After whole session ended, <u>post-experimental interview</u> will be given to ask the paraplegic patients sentiment toward full-body motion with upper-limb tracking

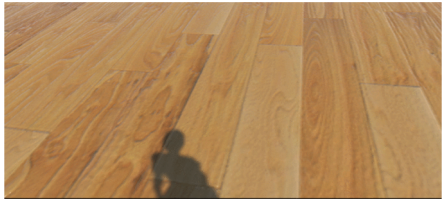


Implementation: User Study

Procedure



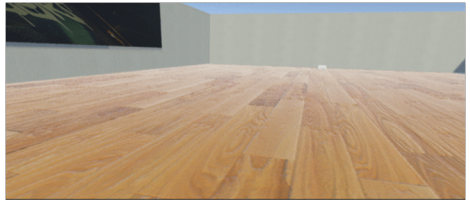
1)



2)

3)

4)



Implementation: User Study

Questionnaire

- R1 "I felt out of my body"
- R2 "I felt as if my (real) *body* were drifting toward the virtual *body* or as if the virtual *body* were drifting toward my (real) *body*"
- R3 "I felt as if the movements of the virtual *body* were influencing my own movements"
- R4 "It felt as if my (real) *body* were turning into an "avatar" *body*"
- R5 "At some point it felt as if my real *body* was starting to take on the posture or shape of the virtual *body* that I saw"
- R6 "I felt like I was wearing different clothes from when I came to the laboratory"
- R7 "I felt as if my *body* had changed"
- R8 "I felt a ____ sensation in my *body* when I saw ____"
- R9 "I felt that my own *body* could be affected by ____"
- R10 "I felt as if the virtual *body* was my *body*"
- R11 "At some point it felt that the virtual *body* resembled my own (real) *body*, in terms of shape, skin tone or other visual features."
- R12 "I felt as if my *body* was located where I saw the virtual *body*"
- R13 "I felt like I could control the virtual *body* as if it was my own *body*"
- R14 "It seemed as if I felt the touch of the ____* in the location where I saw the virtual *body* touched"
- R15 "It seemed as if the touch I felt was caused by the ____* touching the virtual *body*"
- R16 "It seemed as if my *body* was touching the ____*"

Peck, T. C., & Gonzalez-Franco, M. (2021). Avatar embodiment. a standardized questionnaire. *Frontiers in Virtual Reality*, *1*, 44.

(1) **Body Ownership:** (A) I felt as if the virtual body was my own. (B) I felt as if the virtual body I saw was someone else. (C) It seemed as if I might have more than one body. (D) I felt as if the virtual body I saw when looking in the mirror was my own body. (E) I felt as if the virtual body I saw when looking at myself in the mirror was another person.
$Ownership = (1A - 1B) - 1C + (1D - 1E)$

(2) **Agency:** (A) It felt like I could control the virtual body as if it was my own body. (B) The movements of the virtual body were caused by my movements. (C) I felt as if the movements of the virtual body were influencing my own movements. (D) I felt as if the virtual body was moving by itself.
$Agency = 2A + 2B + 2C - 2D$

(3) **Location of the body:** (A) I felt as if my body was located where I saw the virtual body. (B) I felt out of my body. (C) I felt as if my (real) body were drifting toward the virtual body or as if the virtual body were drifting toward my (real) body.
$Location = 3A - 3B + 3C$

(4) **External Appearance:** (A) It felt as if my (real) body were turning into an 'avatar' body. (B) At some point, it felt as if my real body was starting to take on the posture of the virtual body that I saw.
$Appearance = 4A + 4B$

(5) **Response to external stimuli:** (A) I felt that my real body could be affected by the virtual body. (B) I felt as if my real body had changed.
$Response = 5A + 5B$

- Gonzalez-Franco, M., & Peck, T. C. (2018). Avatar embodiment. towards a standardized questionnaire. *Frontiers in Robotics and AI*, *5*, 74.
- Ahuja, K., Ofek, E., Gonzalez-Franco, M., Holz, C., & Wilson, A. D. (2021). CoolMoves: User Motion Accentuation in Virtual Reality. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies*, *5*(2), 1-23.
- Labbe, D. R., Kouakoua, K., Aissaoui, R., Nadeau, S., & Duclos, C. (2021). Proprioceptive stimulation added to a walking self-avatar enhances the illusory perception of walking in static participants. *Frontiers in Virtual Reality*, *2*, 73.

Question	Statement
Located	During the experiment I felt as if my body was located where I saw the virtual body to be.
Ownership	During the experiment I felt that the virtual body was my own body.
Standing	During the experiment I felt that I was standing upright.
MyMovements	During the experiment I felt that the leg movements of the virtual body were my movements.
Agency	During the experiment I felt that the leg movements of the virtual body were caused by my movements.
OtherBody	During the experiment I felt that the virtual body belonged to someone else.
Effort	I felt I had to give extra physical effort when I reached the hill.
Vection	I felt that I was moving through space rather than the world moving past me.
Walking	I felt that I was walking.
Dragged	I felt that I was being dragged.
Sliding	I felt that I was sliding.

Kokkinara, E., Kilteni, K., Blom, K. J., & Slater, M. (2016). First person perspective of seated participants over a walking virtual body leads to illusory agency over the walking. *Scientific reports*, *6*(1), 1-11.

⇒ **7** point Likert-Scale questionnaire

⇒ Revise it to 4 sections: IVBO, Agency, Self-Location, walking motion + preference

⇒ https://docs.google.com/forms/d/1MaQoIgUDuyAVDjdA1uYYo8gAA9ThEMuMZ28vf8w63mI/edit?usp=sharing

Potential Applications

1. VR game for paraplegic patients that needs for lower body movement such as walking, climbing and running
   ⇒ Enable activity that is not possible in real life. We seeks to find
   a positive feedback using our experiment to paraplegic patients.

1. Positive feedback for paraplegic patients so that they can control lower body in VR different from real physical space

1. Rehabilitation of paraplegic patients for improving motility of lower limb

THANK YOU

- Q & A -