Interpretation of Navigation Information Modulates the Effect of the Waist-Type Hanger Reflex on Walking

Yuki Kon*[1], Takuto Nakamura*[1*2], and Hiroyuki Kajimoto*[1]

*[1]The University of Electro-Communications, Japan

*[2]JSPS Research Fellow

ABSTRACT

The Hanger Reflex is a phenomenon in which the head rotates unintentionally when force is applied via a wire hanger placed on the head. This phenomenon is caused by physical pressure on the skin, and the direction of the Hanger Reflex modulated by the direction of skin deformation. A previous study examined the use of the head-, waist-, and ankle-type Hanger Reflex on walking navigation without interpretation of navigation information, and found that the waist-type Hanger Reflex had the strongest effect on walking. However, the existing waist-type Hanger Reflex device is passive; i.e. must be operated by the user, which leads to the necessity of developing a new active type device for use as part of a navigational system. In this paper, we developed a controlled waist-type Hanger Reflex device with four pneumatic actuators. We investigated different interpretations of navigation information on the effect of our device on walking. Our interpretation conditions included "Natural", in which users did not attempt to interpret the navigation information, "Follow", and "Resist", in which they actively followed, or resisted the navigation information, respectively. We confirmed that our waist-type Hanger Reflex device could control the walking path and body direction, depending on user's interpretation of the navigational information.

Keywords: Hanger Reflex, Navigation, Walking, Pseudo-Force.

Index Terms: H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems-Artificial, augmented, and virtual realities; H.5.2 [User Interfaces]: Haptic I/O

1 INTRODUCTION

Maps and signs provide geographical and navigational information in everyday life. However, individuals who are not experienced in reading maps or navigating using landmarks may have difficulty orienting themselves and deciding upon direction to travel. Tools such as Google Maps and iOS Maps combine smartphone map applications and global positioning system (GPS) to assist navigation. Upon setting a destination, the application automatically displays a route from the current location to the destination and navigates while providing feedback about current location. Thus, these technologies provide much more information about location and direction compared with traditional maps.

However, when using these tools on a device, such as a smartphone, while walking, attention is often focused on the screen of the smartphone where the navigation information is displayed. The resulting lack of attention to the environment through which one is moving may lead to accidents, such as collisions and fails.

To reduce the risks associated with focusing on a screen while walking, researchers have proposed walking navigation systems that present auditory and tactile information, such as speech and vibration, respectively, about direction and distance. However, these systems may not necessarily reduce the risks associated with divided attention while navigating through an environment.

To address this problem, several walking navigation methods that do not require interpretation of navigation information have been proposed. This is a method of changing the walking direction by directly affecting the walking of user. However, they have problems in terms of ease of use and safety, as we will discuss.

As a possible tool for walking navigation that does not require interpretation of information, we have investigated the Hanger Reflex, in which the application of pressure to specific body parts elicits involuntary rotatory movements. A previous study showed, among the head-type, waist-type, and ankle-type Hanger Reflex, the waist-type Hanger Reflex has the strongest effect on walking.

In this study, we accomplished two purposes. First, we developed a device with a pneumatic actuator that controls and reproduces the waist-type Hanger Reflex for actual walking navigation, and confirmed its effects. Second, we investigated the effect of the waist-type Hanger Reflex on walking, as modulated by differences in the interpretation of navigation information.

2 RELATED WORK

Studies on walking navigation can be categorized into two groups: those that involve systems that require interpretation of navigation information, and those with systems that do not require interpretation of presented information.

2.1 Walking Navigation with Interpretation of Navigation Information

Walking navigation that involves the interpretation of navigation information by the user involves the interpretation of visual, auditory, tactile or other sensory information. In this type of system, the user must interpret presented information and select a corresponding motion.

2.1.1 Visual Navigation

These navigation systems involve the superimposition of navigation information on the screen of see-through head mounted displays (HMDs) or smartphone cameras. Compared to walking while watching the screen of a smartphone, such systems are considered safer because the line of sight is preserved [1] [2].

2.1.2 Auditory Navigation

Researchers have proposed systems in which navigation information is presented using auditory cue. One of these systems has verbal cues that are updated according to real-time information about street signals, which is especially useful for the visually impaired. Another system gives distance and direction information by changing the sound volume and sound source position presented from a PC or MP3 player according to GPS position [3][4].

2.1.3 Haptic Navigation

Since both vision and audition are used to collect information about

{kon, n.takuto, kajimoto}@kaji-lab.jp

environment while walking, using these modalities for navigation may impair safety. To address this, haptic navigation systems have been proposed. For instance, a walking navigation method [5][6][7][8] may lead the user to a destination via a combination of vibration and GPS information presented through a smartphone, vibration information may also be transmitted via a wearable belt [9][10].

Visual, auditory and haptic information presented as part of a walking navigation system may offer an option that does not impede the user's line of sight. However, such information may still need to be interpreted, and thus may be distracting and potentially unsafe. Thus, it may be advantageous to consider a walking navigation method that uses direct presentation of motion information that does not require interpretation.

2.2 Walking Navigation without Interpretation of Navigation Information

To render the interpretation of navigation information unnecessary, a navigation device would have to directly generate the desired movement. In an ideal system, the user would walk naturally and reach their destination without interpretation of navigation information.

Several walking navigation methods centered around this concept have already been proposed. Some methods use vibrations or skin deformation that elicits a pulling sensation. For instance, one method uses the concept of perceptual nonlinearity to present a navigational direction to a user's hand via a pseudo-force [11][12][13], while another method induces the sensation of a force or skin deformation at the hands, arms, or ears of a user via a mechanical mechanism [14][15][16][17]. Additional proposals include a method in which the center of gravity of the user is modulated left and right via galvanic vestibular simulation [18][19], a method in which an optical flow is presented to the floor using a projector or a lenticular lens [20][21], a technique in which the user wears shoes with a bottom angle that can vary according to navigational information [22], a technique in which functional electrical stimulation is applied to the thigh [23]. Although these methods differ in terms of the level of direct control of muscle activity or of the sensory- motor, they all seek to eliminate the need for symbolic interpretation of navigation information. However, although the method involving a pulling sensation presents a sensation, it is thought that it is not possible to present a motion of a level directly affecting the walking. In addition, the vestibular electrical stimulation method is restricted in terms of the time of use, the optical flow field method in terms of the range in which it can be presented, changing the angle of a shoe sole may produce a risk of falling, and functional electrical stimulation may pose a practical problems in terms of danger of collision due to the lack of self-motion sensation.

2.3 Hanger Reflex

A previous study focused on the Hanger Reflex as a new way to enable walking navigation without interpretation of navigation information. Conventionally, the Hanger Reflex is known as a phenomenon in which the head rotates unintentionally when force is applied via a wire hanger placed on the head (Figure 1). The Hanger Reflex occurs by compressing two opposing points such as the front of the right temporal region and the back of the left temporal region [24] and the direction of motion contributes to the direction of skin deformation [25]. The Hanger Reflex occurs not only at the head, but also at the wrist, waist, and ankle (Figure 2) [26][27].

Although it has been proposed that the Hanger Reflex is elicited by illusion of force caused by skin deformation, it is accompanied by a very clear and involuntary rotation movement compared with the illusion elicited by other forces. If involuntary body rotation motion caused by the Hanger Reflex affects walking, then it is likely suitable

Figure 1: The Hanger Reflex. He wore a wire hanger on his head, Hanger Reflex occurred and his head rotated to the left.

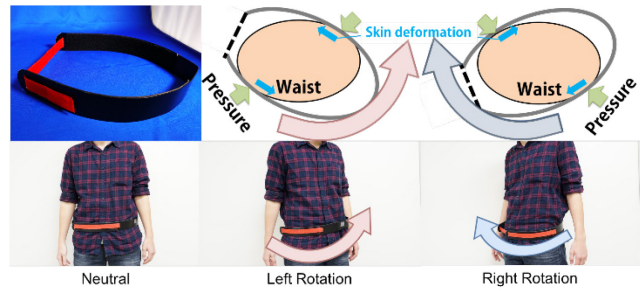

Figure 2: The waist-type Hanger Reflex. Waist-type Hanger Reflex device generates force sensation and involuntary waist rotation.

for walking navigation without interpretation of navigation information. The Hanger Reflex carries a number of additional advantages: It can be presented via a wearable device, there is no restriction on the presentation time and place, it is easy to resist the presented force if necessary, and since it is a rotation force presented to the Yaw axis, the risk of falling is low.

A previous study showed the effect of the head-, waist-, and ankle-type Hanger Reflex on walking, and confirmed that the waist-type Hanger Reflex had the strongest effect [27]. However, the existing waist-type Hanger Reflex device is passive; i.e. rotated by the user. Indeed, to use this phenomenon for walking navigation, a controllable waist-type Hanger Reflex device capable of automatically eliciting left and right turns is required.

3 Experiment 1: Measuring Pressure Distribution

3.1 Experimental Outline

We sought to measure the pressure distribution associated with the Hanger Reflex at the waist. We measured pressure distribution using a device with pressure sensors arranged in an array. This device was attached to the waist and the angle of the chest was measured using an optical motion capture system (Optitrack Prime 13, Natural Point, Inc).

3.2 Measurement System

The pressure distribution associated with the Hanger Reflex at the head and wrist has been measured previously [28]. We adopted the method used by Nakamura et al. to measure pressure distribution at the waist, as follows.

(1) Using a pressure sensor array circling the waist, we obtained the pressure distribution at the waist.
(2) We obtained the angle and position of the chest of the participant.

Figure 3 shows the pressure distribution measurement system used in this experiment. We developed a belt-type pressure

distribution measurement device with 22 film pressure sensors (SFE-SEN-09376, Interlink Electronics Co., Ltd.). The pressure sensor had a lateral width of 43.7 mm. To prevent warping of the device, we attached the back side of the pressure sensor to a 2 mm thick piece of acrylic with dimensions 38.1 mm × 38.1 mm. Additionally, to prevent the waist-type Hanger Reflex device from slipping relative to the pressure distribution-measuring device, we affixed a 3 mm thick natural rubber sponge with dimensions 38.1 mm × 38.1 mm to the surface of the acrylic. The pressure sensors in the array were separated by about 2.5 mm. The total length of the pressure distribution-measuring device was 1015 mm.

We measured the chest angle by attaching a retro-reflective marker to the participant's chest. The marker was tracked using an optical motion capture system (Optitrack Prime 13, Natural Point, Inc). Chest angle and pressure distribution data were obtained simultaneously.

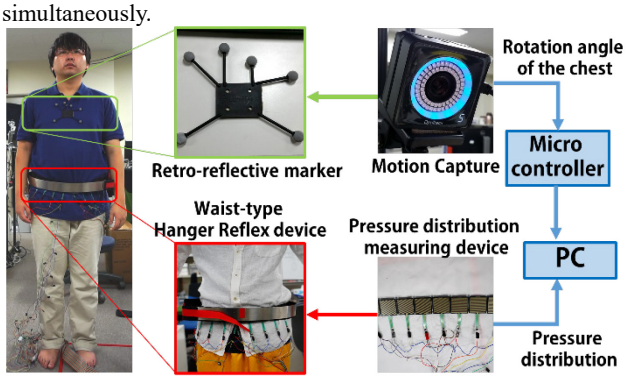

Figure 3: Overall view of measurement system.

3.3 Experimental Procedure

We recruited six men aged 21 to 24 years in our laboratory, and they confirmed that the device elicited the Hanger Reflex at the waist. A pressure distribution measuring device and the Hanger Reflex device were attached to the waist of each participant while they maintained a standing position. The No.1 pressure sensor was located on the navel. The number of pressure sensors used in the pressure distribution measurement device should be adjusted to correspond to the waist circumference of the participants. However, in this experiment, all participants had a similar waist circumference, so we used 21 pressure sensors for the pressure calculations for all participants.

In this experiment, the calibration measurements and main measurements were conducted in the same session. For the calibration measurement, we measured the pressure distribution and the angle of the chest using the pressure distribution-measuring device without the waist-type Hanger Reflex device attached. For the main measurement, both the waist-type Hanger Reflex device and the pressure distribution-measuring device were attached, and we measured both the pressure distribution and the angle of the chest. The time required for each trial consisting of calibration measurement and main measurement was 1 minute.

The waist-type Hanger Reflex device was attached to the waist of each participant by placing at their side and then rotating it according to the position of one sensor. Measurements took place until the waist-type Hanger Reflex device was located halfway up the waist.

During the experiment, the participants were instructed to close their eyes, and when they perceived a force or motion to move naturally without resistance. The experimental duration was about 30 minutes including the explanation time of this experiment.

3.4 Results

According to the methods of Nakamura et al., we performed the following analyses on the obtained data.

(1) We subtracted the pressure and the chest angle values from the calibration measurement from the pressure and chest angle values obtained in the main measurement.
(2) Weighting was performed by multiplying the value of the pressure sensor obtained in (1) by the angle of rotation of the chest in the Yaw axis direction obtained in (1). Data about left and right turns were extracted.
(3) The values obtained in (1) were added and normalized.
(4) (1) to (3) were conducted for all participants.
(5) Data from all participants obtained in (4) were summed and normalized.
(6) Values that contributed to the left rotation and right rotation were respectively displayed on the radar chart.

The graph obtained from the analysis is shown in Figure 4. The numbers on the circumference of the graph refer to the sensors, and the radius represents the degree of contribution of each sensor position to the Hanger Reflex, as indicated by the rotation direction. The larger the contribution, the larger the value. The two sensor numbers that are circled were those with the strongest contribution. The orange ellipse superimposed on the radar chart represents the waist. Figure 4 indicates that the pressure at the positions of sensors 5 and 15 contributed to the Hanger Reflex in the left rotation direction and that the pressure at the positions of sensors 7 and 18 contributed to the Hanger Reflex in the right rotation direction. This shows that the Hanger Reflex is the strongest when pressure is applied to two opposing points, as with the Hanger Reflex of the head and wrist.

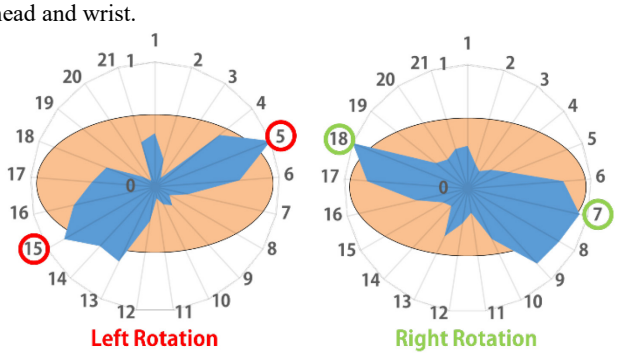

Figure 4: The pressure distribution contributing to the rotation of the waist. (Left: Left rotation, Right: Right rotation)

4 Experiment 2: Control of the Waist-type Hanger Reflex

4.1 Experimental Outline

In this experiment, we tested a Hanger Reflex control device that applies pressure to the points that were found to contribute to the waist-type Hanger Reflex, according to the results of Experiment 1. To measure the angle of the body, we attached a retro-reflective marker to the chest of each participant (upper right of the Figure 5) and used an optical motion capture system (Optitrack Prime 13, Natural Point, Inc).

4.2 Waist-type Hanger Reflex Control Device

We developed a device that produced and controlled the Hanger Reflex using the same pressure distribution confirmed to elicit the Hanger Reflex in Experiment 1.

This device presented pressure using four pneumatic actuators. Deformation of the flexible outer aluminum frame caused shear

deformation of the skin (Figure 5). The size of each pneumatic actuator was 170 mm in length × 120 mm in width, resulting in a displacement of about 5 cm. Each pneumatic actuator was driven by a vacuum pump (KPM27U06A, Koge Electronics Co., Ltd.) with a solenoid valve (SC0415GL, SHENZHEN SKOOCOM ELECTRONIC). The device also included an atmospheric pressure sensor (MIS-2503-015G, Metrodyne Microsystems) and a film pressure sensor (SFE-SEN-09376, Interlink Electronics Co., Ltd.), which was controlled by a microcontroller (mbed1768, NXP). Each pneumatic actuator is driven to the target atmospheric pressure sensor value (1116hpa). To account for individual differences in the waist circumference of the users, we prepared two aluminum frames, 80 cm and 100 cm in length, with adjustable hook and loop fastener straps at both ends.

Figure 5 shows the relationship between the position of the pneumatic actuator driven by our device and the elicited Hanger Reflex. By independently controlling the four pneumatic actuators, as shown in the lower left section of Figure 5, we were able to generate pressure (green arrows) and skin deformation (blue arrows). We expected that this creates pseudo-force and motion (red arrow) in the direction of skin deformation.

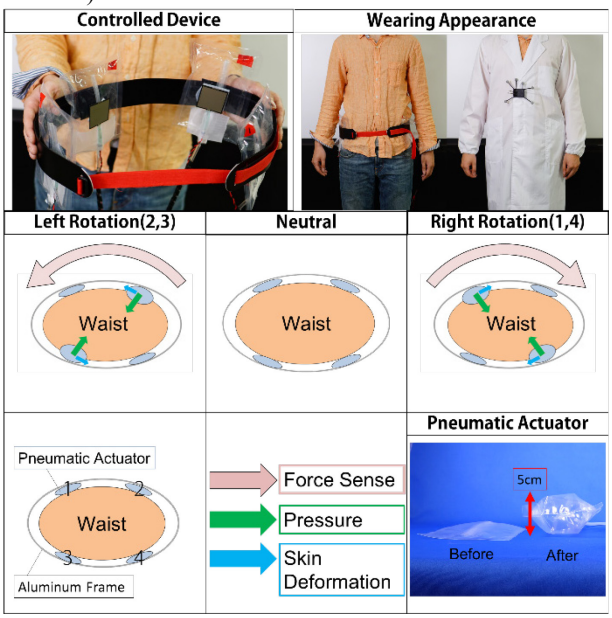

Figure 5: Control of the waist-type Hanger Reflex.

4.3 Experimental Condition and Procedure

We recruited six participants (four males, two females, 21 to 25 years old) in our laboratory. Prior to the start of the experiment, the experimenter adjusted the positions of the pneumatic actuators on the developed device. The developed device was then attached to the waist of the participant. The participant wore a white coat over the device with a retro-reflective marker attached so that the displacement of clothing by the device did not affect the chest measurement. The experiment was conducted with the participants in a standing position. Participants were randomly assigned to three conditions: no pressure (Neutral), left rotation, and right rotation, as shown in the Figure 5, for a total of 15 trials. The time required for each trial was about 1 minute. During the experiment, participants were instructed to close their eyes and to move naturally without resistance when they perceived force or movement. The experimental duration was about 40 minutes including the explanation time of this experiment.

4.4 Results

From the perspective of the participant, movement towards the rear was termed movement in the x-axis positive direction, movement up was that in the y-axis positive direction, and movement to the right was that to the z-axis positive direction. The pressure sensor and chest angle data were measured at 20 Hz, and processed using a moving average filter with n = 10. Figure 6 shows the value of the chest angle in the Yaw axis direction for all participants under each condition. The horizontal axis on the graph shows the experimental conditions. The vertical axis shows the angle [degree] of movement of the chest in the Yaw axis direction. We performed a one-way analysis of variance (ANOVA) and found significant differences between the Hanger Reflex conditions ($F(2,87)=88.493$, $p<0.001$). Multiple comparisons with the Tukey-Kramer method revealed a significant difference between the conditions, as shown in Figure 6. Figure 7 shows the values of the atmospheric pressure sensor and the film pressure sensor at each pneumatic actuator, as well as the chest angle for a representative participant in one trial in the left turn condition. The horizontal axis represents time [s], the first vertical axis represents the normalized sensor value, and the second vertical axis represents the angle [degree] of the chest in the Yaw axis direction.

From Figure 6, we can see that the chest rotated left and right in Left and Right conditions (left: median value is -17.7 degree, right: median value is 16.2 degree). As shown in Figure 7 as the value of the pneumatic actuator increased, the value

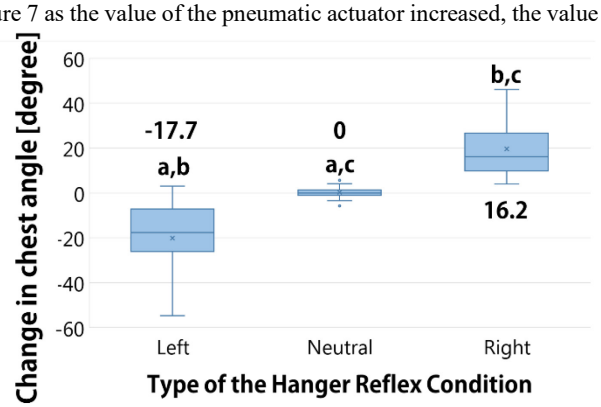

Figure 6: Chest angle in the Yaw axis direction under each Hanger Reflex condition. There is a significant difference ($p<0.001$) between the conditions in which common alphabets are indicated. The median value is shown in the figure.

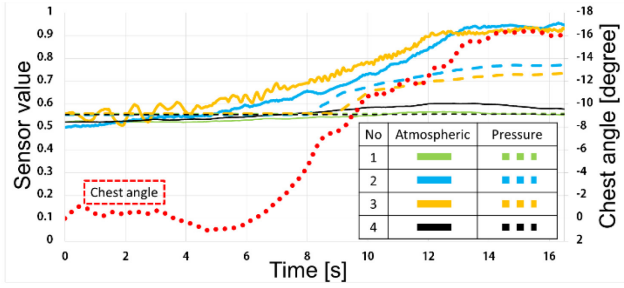

Figure 7: Chest angle, pressure sensor, and atmospheric sensor data from one participant in one trial. The solid line shows sensor value of atmospheric sensor. The dotted line shows sensor value of pressure sensor. The sensor number corresponds to the pneumatic actuator in Figure 5. Red dotted line shows chest angle from one trial of one user. As the values of No.2 and No.3 atmospheric sensors increase, it can be confirmed that the values of No.2 and No.3 pressure sensors increase, and the chest angle of the user changes.

of the pressure sensor increased and the value of the chest angle changed.

The above data indicates that we succeeded in reproducing the Hanger Reflex on the waist by pressuring the two opposing points measured in Experiment 1 using the pneumatic actuator.

5 Experiment 3: Influence of Interpretation of Navigation Information on Walking

5.1 Experimental Outline

In Experiment 2, we developed a device for controlling and reproducing the Hanger Reflex on the waist. In Experiment 3, we investigated the influence of our waist-type Hanger Reflex control device on walking. Previous walking navigation studies had evaluated walking navigation with and without interpretation of navigation information. For instance, a previous study confirmed that the waist-type Hanger Reflex would enable walking navigation without interpretation of navigation information. However, even if a participant is asked not to interpret the information, this condition still creates a state in which the user is aware of the fact that the sensation is being presented. The best way to address this is to create a number of interpretation conditions and compare them, because all conditions will involve some degree of awareness of the presentation of information.

Therefore, in Experiment 3, we investigated the type of walking influence by both confirming that our device influenced walking and by examining user's interpretations of the waist-type Hanger Reflex.

Participants wore the developed waist-type Hanger Reflex control device and walked while wearing an eye mask and headset. We attached retro-reflective markers to the head and chest of the participant to measure the position and angle of these body parts via an optical motion capture system (Optitrack Prime 13, Natural Point, Inc). We removed the belt of the trousers and put our waist-type Hanger Reflex control device on the position of the belt.

5.2 Waist-type Hanger Reflex Control Device

In this experiment, we used a device that was improved from the waist-type Hanger Reflex control device used in Experiment 2 (the left and center of Figure 8). There are two improvements, the addition of a vacuum pump (SC3701PML, SHENZHEN SKOOCOM ELECTRONIC) and a solenoid valve (SC415GF 6.0V, SHENZHEN SKOOCOM ELECTRONIC). Additionally, the dimensions of the pneumatic actuator were changed from Experiment 2 (vertical length of 170 mm × width 120 mm) to length 75 mm × width 120 mm. The pneumatic actuator was driven by a vacuum pump and a solenoid valve. Each pneumatic actuator was independently controlled so as to have a constant pressure sensor value. The sensor values were transmitted to a PC and recorded. We set the target this sensor value to clearly produce the waist-type Hanger Reflex.

Figure 8: Left: Improved controlled device. Center: Control unit with built-in vacuum pumps and solenoid valves etc. Right: Measurement device of head. It has retro-reflective marker attached.

5.3 Measurement System

In this experiment, we measured the positions and angles of the head at rest and during walking. We attached retro-reflective markers to the head of each participant, as shown in the right of Figure 8, and measured movement using an optical motion capture system (Optitrack Prime 13, Natural Point, Inc). The experiment was conducted in a quiet laboratory with a walking area of 5 m × 3 m.

5.4 Evaluation

For each trial, the participants completed the following items, which measured the perception of walking curvature during walking.

A) Did you perceive any active curvature in your walking trajectory?

B) Did you perceive any passive curvature in your walking trajectory?

Participants responded using a five-stage Likert scale, where 1 corresponded to "not at all active/passive", and 5 to "extremely active/passive". Active curvature indicated that the participants agreed with the phrase "I turned by myself while walking", and passive curvature corresponded with the phrase "an external force made me turn while walking".

5.5 Procedure

We recruited six participants (five males, one female, 21 to 24 years old) in our laboratory. Prior to the start of the experiment, we asked the participants to practice by wearing an eye mask and undergoing walking exercises while white noise and a 100 bpm metronome sound were presented though a headset. We also confirmed that the control device elicited the waist-type Hanger Reflex.

The flow of one trial of this experiment is as follows.

(1) Standing at the start position, we attached the waist-type Hanger Reflex control device and retro-reflective markers to the participant.
(2) We attached the earphones and eye mask to the participant.
(3) White noise was presented and measurement began.
(4) The waist-type Hanger Reflex was presented via the control device.
(5) The amount of waist-type Hanger Reflex was controlled by a prescribed sensor value. This sensor value (1174 hpa) has been confirmed by the authors that waist-type Hanger Reflex occur sufficiently.
(6) A 100-bpm metronome sound was presented and the participant started walking when they were ready. The participant had been instructed to match their walking with the metronome sound.
(7) The white noise and metronome sound stopped to signal that the participant had reached the boundary of the walking area. The participants had been instructed to stop immediately upon hearing this signal. The waist-type Hanger Reflex control device was set to a Neutral state.
(8) The earphones and eye mask were reattached, and the participant returned to the start position.
(9) The trial was repeated so that the participant could make a subjective assessment.

The time required for one trial was about 1.5 minutes. The experimental duration was about 90 minutes including the explanation time of this experiment.

5.6 Experimental Condition

There were three experimental waist-type Hanger Reflex conditions and three interpretation condition.

The Hanger Reflex condition was repeated five times, for a total of 15 trials in 1 set. There were three different interpretation conditions, for a total of 45 trials. The order of Hanger Reflex conditions was randomly determined, and there were six different sequences in which the interpretation conditions were presented. Care was taken to avoid presenting the interpretation conditions in the same order twice to any participant.

5.6.1 Interpretation Condition

A previous study [27] confirmed that the waist-type Hanger Reflex influences walking when individuals walk naturally without resisting the perceived movement on the waist. However, there are three possible interpretations of the waist-type Hanger Reflex for use as navigation information during walking. The first interpretation condition is Natural (N) in which individuals walk naturally without resisting the perceived Hanger Reflex. We defined this as walking navigation without interpretation of navigation information. The second condition is Follow (F), in which an individual walks to "Follow" the perceived Hanger Reflex. In this condition, walking navigation is occurring with interpretation of navigation information. The third condition is Resist (R), in which an individual walks to resist the perceived Hanger Reflex. This third condition is important from the viewpoint of safety in practical navigation, since if we cannot resist the navigation information, we may not avoid collisions. In the experiment, the third condition R is that when the Hanger Reflex on the waist is presented before the start, the participants were asked to walk to the direction of the front of the body, which might have been rotated by the Hanger Reflex on the waist.

5.6.2 Hanger Reflex Condition

The three waist-type Hanger Reflex conditions were Neutral (N), Left (L), and Right (R). The Hanger Reflex was not generated in the Neutral condition, and the Left and Right conditions involved left or right rotations of the waist by the Hanger Reflex, respectively.

The two conditions of interpretation (I) and Hanger Reflex (H) are expressed as I × H. For example, when the interpretation condition is F, and the Hanger Reflex condition is L, it is written as FL. There is a possibility that walking distance and walking time may differ under each condition and each participant.

5.7 Results and Discussion

5.7.1 Change of Walking Direction

Figure 9 shows the representative path of one user. Figure 10 shows the direction change under each condition. This is $\tan^{-1}(y/x)/y$ [degree/m] when the start position is (0, 0) and the goal position of the participant is (x, y). A positive value on the vertical axis of the graph indicates a change in the direction to the right, and a negative value indicates a change in the direction to the left. We performed a one-way analysis of variance (ANOVA) and found significant differences between the experimental conditions ($F(8,261)=18.72$, $p<0.001$). Multiple tests using the Tukey-Kramer method, revealed significant differences, as shown in Figure 10.

From Figure 10, we found a significant difference between each Hanger Reflex condition in the interpretation condition Follow (F). In addition, when the interpretation condition was Natural (N), we found a significant difference between L or R Hanger Reflex conditions. We found no significant differences among the Hanger Reflex conditions when the interpretation condition was Resist (R). In addition, when the Hanger Reflex condition was L, we found a significant difference among the interpretation conditions.

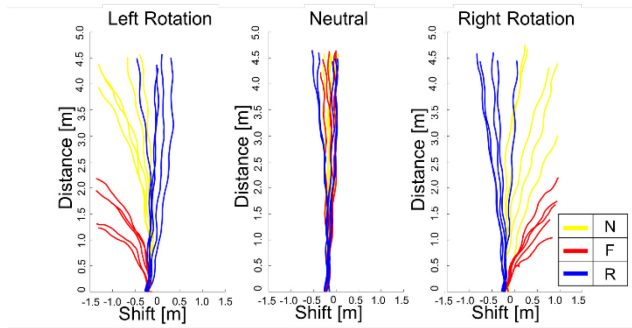

Figure 9: Plots of the raw data of one user. Yellow line shows walking "Naturally", red line shows walking "Follow", and blue line shows walking "Resist".

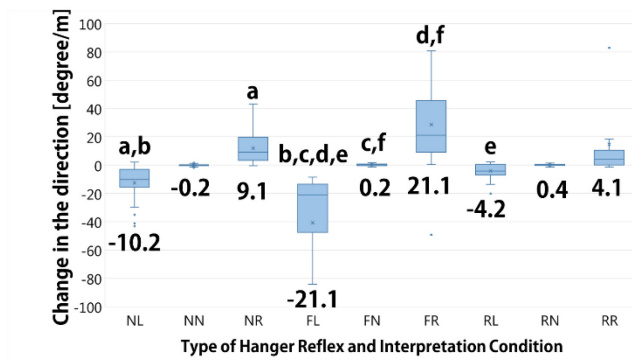

Figure 10: Change in the direction (degree per meter) for each Hanger Reflex and interpretation condition. There is a significant difference ($p<0.001$) between the conditions in which common alphabets are indicated. The median value is shown in the figure.

As a result, we confirmed that it is possible to turn to the left and right while walking in interpretation conditions Natural (N) and Follow (F). In addition, our data suggest that the guidance regarding direction can change depending on the interpretation condition.

5.7.2 Change in Body Angle at Rest

Next, we look at the result of each condition based on the angle of the participant head and chest. Figure 11 shows the amount of rotation at rest in each condition. Specifically, this figure shows the change in the angle of the participant head and chest before walking, in experimental steps from (3) to (6). A positive value on the vertical axis of the graph indicates a rightward rotation and a negative value indicates a leftward rotation. We performed a one-way analysis of variance (ANOVA) and found significant differences between the experimental conditions ($F(8,261)=21.887$(head) and 34.257(chest), $p<0.001$). Multiple tests using the Tukey-Kramer method, revealed a significant difference, as shown in Figure 11.

From Figure 11, we found a significant difference in the head and chest among the Hanger Reflex in the N and F interpretation conditions. Moreover, we found a significant difference in the head between the R Hanger Reflex condition in the R interpretation condition and the L Hanger Reflex condition in the R interpretation condition. Also, we found a significant difference in the chest among the Hanger Reflex conditions in the R interpretation condition. However, we found no significant differences in the head and chest among the Hanger Reflex, no matter which interpretation condition.

Our data indicate no significant differences in the amount of head and chest rotation at rest in a single Hanger Reflex condition for each interpretation condition.

5.7.3 Change in Body Angle during Walking

Figure 12 show the amount of rotation during walking under each condition i.e., the difference in angle between the start (6) to end (7) of walking. A positive value on the vertical axis of the graph indicates a rightward rotation and a negative value indicates leftward rotation. We performed a one-way analysis of variance (ANOVA) and found significant differences between the experimental conditions ($F(8,261)=51.752$(head) and 51.77(chest), $p<0.001$). Multiple tests using the Tukey-Kramer method confirmed a significant difference, as shown in Figure 12.

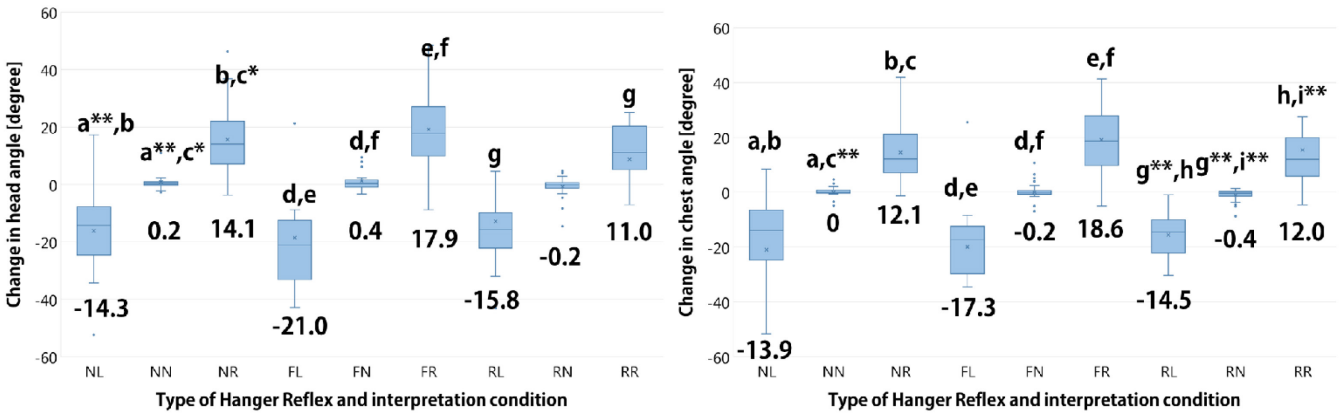

Figure 11: Left: Amount of head rotation at rest. Right: Amount of chest rotation at rest. There is a significant difference (e.g. a:p<0.001, a**:p<0.01, a*:p<0.05) between the conditions in which common alphabets are indicated. The median value is shown in the figure.

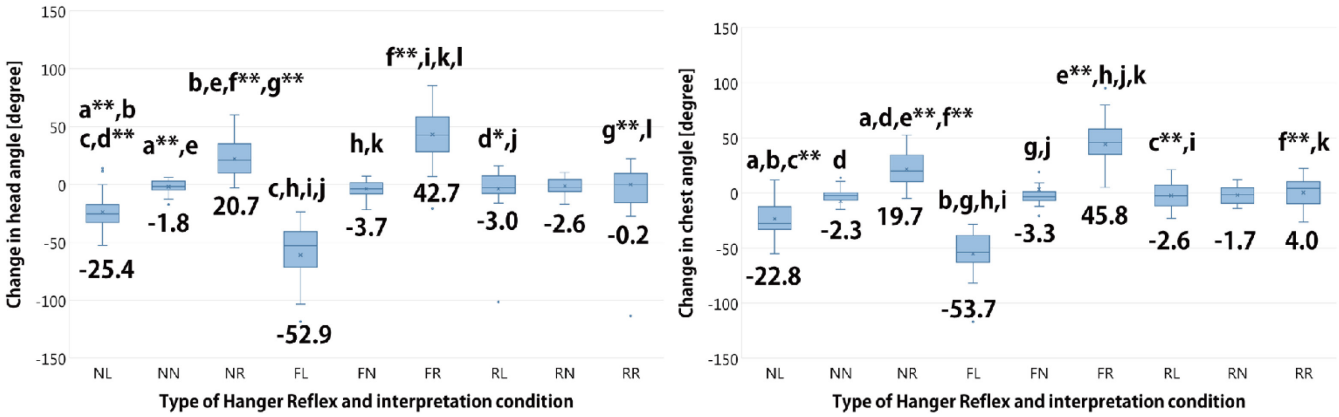

Figure 12: Left: Amount of head rotation during walking. Right: Amount of chest rotation during walking. There is a significant difference (e.g. a:p<0.001, a**:p<0.01, a*:p<0.05) between the conditions in which common alphabets are indicated. The median value is shown in the figure.

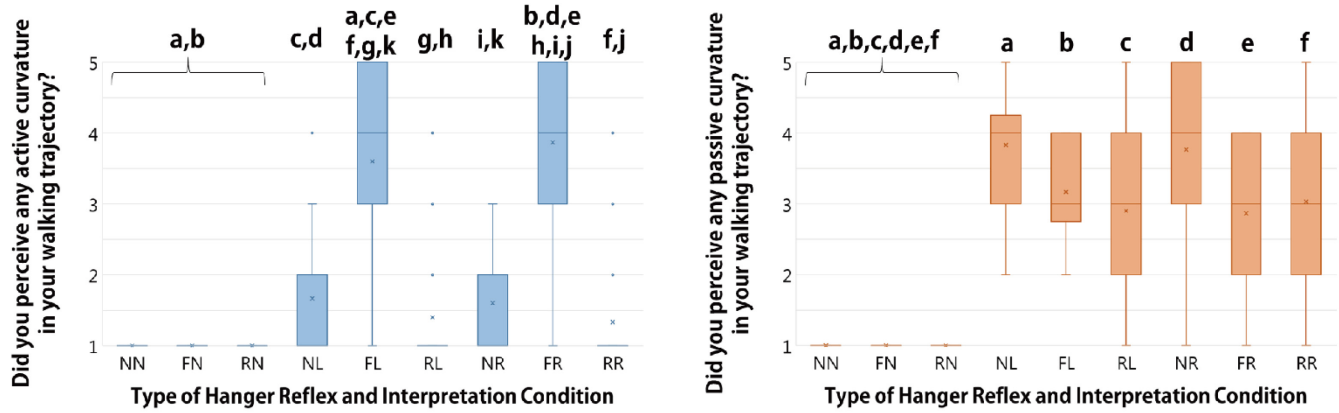

Figure 13: Results of subjective evaluation. Left: Answers to the item “Did you perceive any active curvature in your walking trajectory?”. Right: Answers to the item “Did you perceive any passive curvature in your walking trajectory?”. There is a significant difference (e.g. a:p<0.001) between the conditions in which common alphabets are indicated. The median value is shown in figure.

As shown in Figure 12 , we found significant differences in the head and chest among the Hanger Reflex conditions in the N and F interpretation condition. However, we found no significant differences in the head and chest among the Hanger Reflex conditions in the R interpretation condition. Also, we found significant differences in the head and chest among the interpretation conditions in the R and L Hanger Reflex conditions.

This indicates that when the interpretation condition was N and L, the direction of the head changed and the participant walked in an arced trajectory, and when the interpretation condition was R, the direction of the head remained stable, and the participant walked straight in a straight trajectory.

Thus, the amount of rotation of the head and chest changed during walking due to differences in the interpretation conditions.

5.7.4 Subjective Evaluation

Figure 13 shows the results of the subjective evaluation of active and passive walking curves under each condition. This walking curve occurs from (7) to (8) until stopping. Friedman's tests showed a significant difference, as shown in Figure 13.

As shown in left of Figure 13, we found a significant difference between the L and R Hanger Reflex conditions and the N Hanger Reflex condition in the F interpretation condition. Moreover, we found a significant difference between the L Hanger Reflex condition in the F interpretation condition compared with that in the N and R interpretation conditions. Similarly, we found a significant difference between the R Hanger Reflex condition in the F interpretation condition compared with that in the N and R interpretation conditions. However, when the interpretation condition was R, we found no significant differences among the Hanger Reflex conditions. This indicates that subjective active perception changes depending on the difference in the interpretation of rotational force induced by the Hanger Reflex.

As shown in right of Figure 13, we found a significant difference between the N Hanger Reflex condition and the L and R Hanger Reflex conditions, no matter which interpretation condition. This indicates that when the Hanger Reflex was presented at the waist, it was perceived as a passive influence on walking curvature.

Focusing on each interpretation condition, the interpretation conditions that were not associated with the perception of active walking curvature were N and R, which elicited a strong passive feeling, while the F interpretation condition was strongly associated with the perception of active walking curvature. This indicates that walking curvature perceived in any interpretation condition had a certain passive feeling, and that it may be difficult to develop a walking navigation system that influences the trajectory of walking without being noticed. Also, even though the interpretation condition R produced a straight walking trajectory, i.e., the participant actively walked against the Hanger Reflex, they perceived the influence of walking as passive. This means that perceived (subjective) walking curves may exist even when the actual walking trajectory is straight.

Our experimental results indicate that the waist-type Hanger Reflex can elicit a pseudo-force of rotation direction as navigation information. This can lead to a change in walking direction due to changes in the orientation of the body during walking. In addition, our data indicate that changes in walking trajectory and active and passive perception of walking curvature can occur in the following interpretation conditions: naturally, follow, and resist.

6 Limitations

6.1 Generalizability of Results

Each experiment in our study had a low number of participants with narrow demographics (Table 1). Therefore, although we found significant effects, the extent to which these effects can be generalized is not clear. In our experience at the demonstrations, we confirmed that the waist-type Hanger Reflex occurs in elderly people, and people who are overweight. However, the waist-type Hanger Reflex has not been fully explored in other populations, such as children.

6.2 Proposed Method

Disadvantages of pneumatic actuators include slow responses, noise, and battery consumption. Since the Hanger Reflex itself is a phenomenon with a relatively slow response, we found it appropriate to use a pneumatic actuator. We did not receive any reports that the pneumatic actuator seemed “slow” or “big” from the participants. Furthermore, in real-world applications, predictions via GPS software may be available, which could enable a faster response. To solve the issue of noise, it may be possible to store the components in a case, similar to commercially available blood pressure monitors that have comparable pumps and produce minimal noise. Finally, the pump is an actuator with heavy battery consumption. However, in real-world conditions, the pump would be activated only when the user approaches a corner.

Table 1 Participant demographic information. The circles indicate participation in each experiment.

		Participant									
		A	B	C	D	E	F	G	H	I	L
Experiment	1	○	○	○	○	○	○				
	2	○		○				○	○	○	○
	3	○	○	○	○				○		○
Participant's Information	Age	21	21	21	23	22	24	25	24	23	23
	Height [m]	1.59	1.7	1.73	1.74	1.64	1.7	1.7	1.62	1.72	1.75
	Weight [kg]	60.3	56.5	63.4	67	68	75	75	50	50	53

7 Conclusions

In this study, we focused on the Hanger Reflex, which generates clear and involuntary rotation movements, as a potential component of a walking navigation system that does not require interpretation of navigation information. A previous study investigated the effect of the head-, waist-, and ankle-type Hanger Reflex on walking, and confirmed that the waist-type Hanger Reflex had the strongest effect.

In this paper, we accomplished two objectives. First, we developed a device that uses a pneumatic drive to control and reproduce the Hanger Reflex on the waist for actual walking navigation, and confirmed its effects. Second, we investigated the effect of the waist-type Hanger Reflex on walking, as modulated by differences in the interpretation of navigation information. Our experimental results indicate that the developed device could control walking direction, and that the effect of the device is modulated by the interpretation conditions.

We have a number of plans for future research. Adding to the improvements discussed in section 6, we plan to operate the device in a real-world scenario; i.e. walking to an unknown destination in a town. To do so, we will manufacture a compact wireless waist-type Hanger Reflex control device incorporating a battery. Then we will conduct an outdoor experiment, in which the users will not be informed of the destination, such that walking and destination are controlled by the proposed device.

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