The Effect of Non-Forwards Locomotion during Redirection in Virtual Environments

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ABSTRACT

Redirection is an interesting technique used in virtual reality applications that alters the user's sense of position & orientation to reduce the amount of physical space needed to traverse large expanses of virtual worlds. While steering has been proved to be an effective method of redirection, all studies have been found to only test forwards locomotion. In video gaming applications and human locomotion in the physical world, natural movement included strafing and walking backwards. This study experiments with a system that has a user walk in virtual and physical reality in various cases in order to evaluate if redirection techniques are affected by locomotion type. The position and orientation of the user was shifted using steering redirection techniques, specifically with curvature gain algorithms which force the user to deviate from a straight path in physical reality. Four cases were tested in which the user walked forwards and backwards away from the goal, looking constantly over their shoulder and with occasional glances behind their back. It was found that using curvature gain for redirection is effective for walking in both forwards and backwards locomotion, however, differences between deviation effects in the four test cases were not statistically significant.

CCS CONCEPTS

• **Human-centered computing** → *Virtual reality*; Graphics input devices; Empirical studies in HCI; • **Computing methodologies** → Virtual reality;

KEYWORDS

redirection, walking, virtual environments

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1 INTRODUCTION

Current virtual reality games and virtual environments in general are limited to a small space or are designed for stationary interactions due to physical limitations. For users with limited space, a more enriched experience can be provided by using redirection techniques which allow users to see and walk in a larger virtual environment within a smaller real space. The current majority of commercial users of virtual reality are video gamers whose key movements consist of not only walking forwards but also walking backwards and strafing. Techniques involved in redirection have been tested only in controlled, research areas in which the user only walks forward. Suggested future testing have been included in the presentation of findings[3], however, the parameters of backwards walking in redirection has yet to be defined.

Forwards and backwards locomotion both is linear and one dimensional in essence and deviation from a straight line can be easily compared. Moreover, generalised redirection techniques such as repositioning the target end location slightly off-centre from the user's rotational position during locomotion can be applied when both the body and head are facing forward. However, the user's repositioning techniques may change when moving backwards due to a heightened sense of awareness and caution. Additionally, their gait patterns will change, loading their cognition with more concentration in the actual locomotion than subtle environmental shifts. Walking backwards will require either blind aim in the direction of motion, or constant head turning to reposition the user trajectory properly. The increased shifting in visual focal point may slow down the user's cognition and allow the system to inject more environmental shifts when the user is focused on other tasks. Furthermore, during backwards locomotion, there could be further conflict between cranial vestibular sensory inputs, visual inputs, and proprioceptive input. In order to achieve a full range of movement in locomotion in a virtual environment, it is necessary to explore the differences in redirection cue effects between moving forward and backwards.

2 BACKGROUND

2.1 Redirection Techniques

Changing the viewpoint in a virtual environment without bringing the user's attention to position or orientation can be done in three ways: steering, distraction, and deterrents. Distraction, classically used in stage magic, is defined as pulling the user's visual focus away from their goal while the change occurs. This area of research has been proven to work in both static and moving, virtual and physical environments. Without eye tracking, it may be difficult to detect the user's exact visual focus is at any given time and thus this redirection type will not be addressed. Deterrents are static objects such as walls and fences that prevent the user from crossing a non-physical boundary in the virtual environment. This type of attentional unawareness can only be taken advantage of outside the user's full field of view as they are large and fairly noticeable. As deterrents also decrease the virtual room size, the goal of having a larger spacious virtual environment is also defeated. Thus, steering is chosen as the implementation method of this study.

2.2 Steering Techniques

A plausible mechanism for why steering works well for redirection is limitations in human visual acuity during locomotion. The human eye's ability to track objects when moving depends on the speed of movement sensed by the low resolution vestibular sense - i.e. easily shifted without noticeable movement - in conjunction with eye movement. The faster the movement, the less focal the object will become. The implementation used in this study will allow the user's position and orientation is altered proportional to the speed at which they move. The position in the real world is altered with a set of predetermined gain values for translation and rotation to steer the user off course and force them to correct their virtual position and orientation by changing their real-world path. A steering redirection technique proved to be effective[3][4] involves using positional kinematic gains to map physical movement to the virtual environment in a scaled manner such that the amount of movement in the virtual environment is greater than physically achieved. Three different types of quantified gain measurements are considered: translational, rotational and curvature.

Translation gain is defined as the proportion of mapped virtual world translation ($T_{virtual}$) to tracked real world translation (T_{real}) where T_{real} detects a change in the user's real world position. Generic gain for translation movement can be quantified by three vectors - strafe vector s, up vector u and direction of walk w. Our investigation will primarily focus on applying gain as it relates to the direction of walk w and using this altered value to affected the strafe vector s.

Rotational gain adjusts the user's yaw rotation where the amount of virtual world rotation is proportional to real world rotation with an added gain. This alters the expected orientation of the user, forcing them to turn further or less than expected when turning. An offset can be applied in the positive and negative direction to slowly increase the rotation in one direction.

Lastly, curvature gain denotes the resulting bend of a real path; this can be used to move the user along a curved real world pathway while staying in a straight virtual path as seen in Figure 1. This uses a combination of translation and rotation gain such that the user's rotation and strafe is altered by a gain proportional to their walking movement w. This allows redirection to occur even with limited head rotation in contrast to using only rotational gain[4]. In this case, regardless of forwards or backwards movement, the altered path should be repeatable back and forth.

This in combination with Razzaque's original method of redirection[2] was used to develop the experiments simplfied curvature gain algorithms.

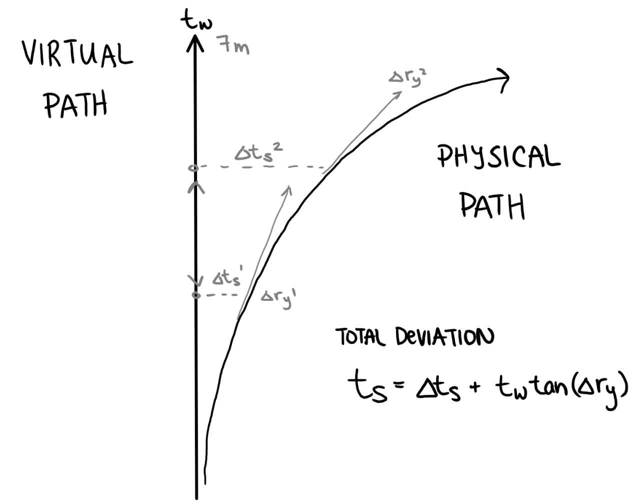

Figure 1: Top-down representation of expected deviation based on altering strafe and rotation vectors.

3 EXPERIMENTAL DESIGN

3.1 Design Constraints

It is proposed that a system be designed in order to compare the effectiveness of current redirection techniques between walking forwards and backwards. This system will serve as a proof-of-concept prototype to be combined with forward walking techniques to increase the authenticity of virtual environments. A pilot study will be performed to evaluate the system's functionality. Feasibility constraints for the design of the initial prototype include time-frame (2 months), resource limitations, and general knowledge requirements.

3.2 Scope

This project is limited to specifically comparing the effects of redirected walking in forwards and backwards locomotion. As such, the overall virtual reality experience was fairly limited. Simple environments were produced which may not contain much detail and in order to speed up development, third party code was used whenever possible.

3.3 Technical Setup

This study uses the Oculus Rift DK2 head mounted display (HMD) and a virtual environment developed in OpenGL in combination with position tracking with OpenCV to determine the real position of the user and update their corresponding altered virtual world movement in real-time. A PlayStation Eye camera is used to track the user's position by detecting a spherical green marker placed above their head which can be seen in Figures 2 and 3. The OpenCV tracking application could be seen in Figure 5 The x-y movement was transferred via Bluetooth from a laptop running the position tracking software to the computer connected to the OpenGL application. The virtual environment could be seen in Figure 4, which updates the user's position in the virtual world that is displayed in

Figure 2: Rift with Green-colored Marker

Figure 3: Camera with Tripod Setup

the HMD. The user's head rotational movement was measured directly from the sensors in the Oculus Rift, which proved to be fairly accurate. Equations 1, 2, and 3 were used to implement steering gain:

$$T_w = T_{w_{prev}} + \Delta T_w \quad (1)$$

$$T_s = T_{s_{prev}} + \Delta T_s + \alpha T_w \quad (2)$$

$$R_y = R_{y_{prev}} + \Delta R_y + \beta T_w \quad (3)$$

T_w is translation in the walking direction, Ts is translation is the strafing/deviation direction orthogonal to T_w, and R_y is the yaw rotation of the user's viewpoint. α is the translational component of curvature gain and β is the rotational component of the curvature gain. Through experimentation and preliminary testing, the gain values were optimised to $\alpha = 0.15$ and $\beta = 0.0075$. For a walking distance of 7 m, this equates to a minimum of 1.41 m strafe deviation, not accounting for coupling effects between rotation and translation

In the previous related works[4][2][5], curvature gain was used to determine sensitivity to redirection techniques and was altered to be applied in simplicity. Rotation gain proved to be ineffective during testing due to limited head rotation when walking in a straight line. Contrarily, in the case where the user occasionally

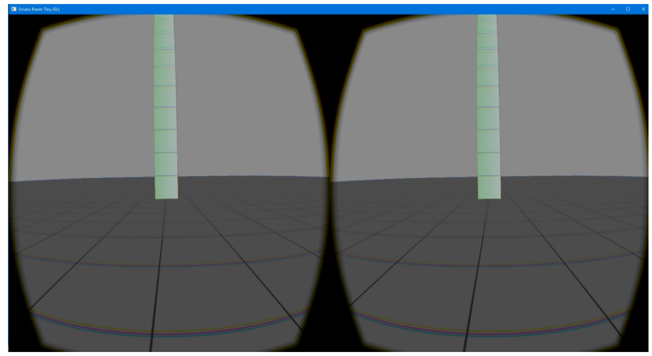

Figure 4: OpenGL Virtual Environment as seen in Oculus Rift

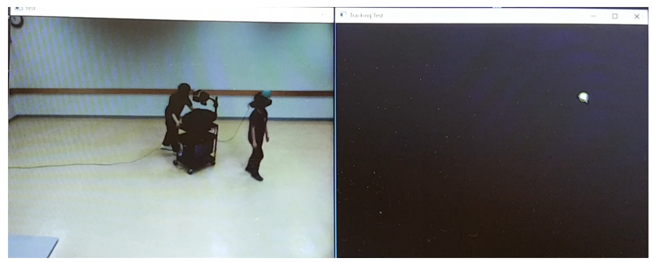

Figure 5: OpenCV Camera Tracking Application

looked over their shoulder while walking backward, the effect of rotational gain was too strong to be considered effective in short distances. The strafe deviation from a straight walking path is used as the metric of evaluation to compare differences in 1-to-1 mapping and applied gain, as well as the effective differences between walking forwards and backwards.

The key metric to be evaluated are deviation from the centre line - a straight line defined in physical space. This will be simply measured with physical markers by the experimenter and measurements will be recorded with a measuring tape; additional metrics will include time to complete and perception of distance travelled. It is noted that the users will not be told to meet a specified time for completion but the time period will be noted to check for possible outliers. The perception of distance will be evaluated qualitatively during the post-trial survey questionnaire, in addition to the Kennedy's simulator sickness effect.

4 EXPERIMENT METHODOLOGY

Prior to testing, users were asked for general demographic data as well as if they had past experience with virtual reality and if they have had previous experiences of motion sickness. It was hypothesised that participants who are more reliant on their vestibular senses or participants with higher resolutions in their visual acuity may be able to identify the redirection cues more easily and find them distracting or disorienting. Additionally, any visual aids which are typically worn (i.e. glasses) by the user were noted.

The study consists of four test cases: a control in which the user walked forwards and three backwards walking test cases. One

Table 1: Mean and Standard Deviation for Control and Gain Redirection Techniques

		F	B - FF	B - OS	B - OL
Control	μ	17.36	10.21	18.86	16.57
	σ	13.79	14.54	17.71	10.54
Gains	μ	242.71	277.14	239.29	241.14
	σ	29.43	38.96	39.11	32.09

where the user walks away from the goal in a straight line, one where the user walks backwards with their head turned around towards the goal, and lastly one where the user is instructed to occasionally turn while walking to confirm they are walking towards the goal. Each test case was run once with 1-to-1 mapping as a control case, and once in all four cases with equal gain values. All 8 trials were run in a randomly generated order to ensure the user was blinded to the effect. It is noted that when the participant walked away from the goal, the translational gain algorithm needed to be switched to the negative strafe direction to deviate in the same direction.

7 of participants were tested, 6 male, 1 female within the range of 21 to 27 years of age. All the participants were right handed and preferred to look over their right shoulder when walking backwards. All applied gains deviate the user in the positive âĂŸstrafe vector' direction. Prior to and after each session, a survey was also conducted to check for possible confounding variables such as susceptibility to simulator sickness. After each test case, the user was asked if they noticed any redirection effects. At the end of the experiment, Kennedy's Simulator Sickness test[1] was also conducted to ensure user safety and comfort with the experiment.

For safety of participants, experiments were conducted in a large open area with a level floor and no obstacles. Experimenters were on standby near the user to aid them in case they deviated too far from the path and may collide into an obstacle as well as if the user felt uneasy. Users were instructed to walk at their own pace to ensure they do not stumble or fall along the way.

5 RESULTS

5.1 Quantitative Results

The measured displacement data collected from physical environment measurements was analyzed in order to determine the performance of each technique. A table of mean and standard deviation values for both control and redirection cases could be seen in Table 1. First, four one-way ANOVA test were performed comparing each redirection technique to its control test case. In Figures 6, 7, 8 and 9, it can be easily seen that the redirection techniques functioned as expected and successfully managed to shift the user's position away from the actual objective. These results were proven to be statistically significant with all four having p-values < 0.01. Using steering in curvature gain is effective for both walking forwards and backwards.

Statistical analysis was further used to compare the forward redirection techniques to the three backward locomotion cases. It was hypothesised that all four techniques should have similar

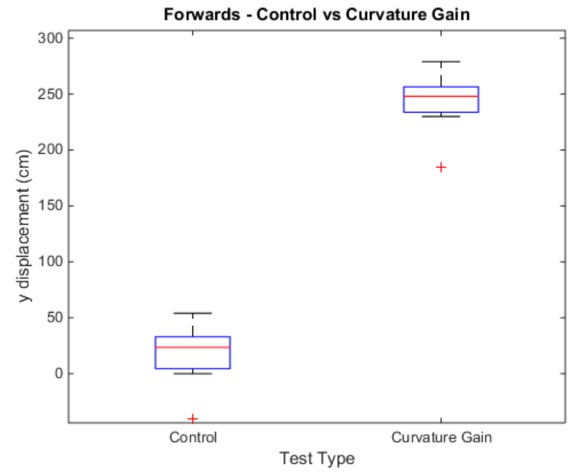

Figure 6: Box Plot of Forward Techniques

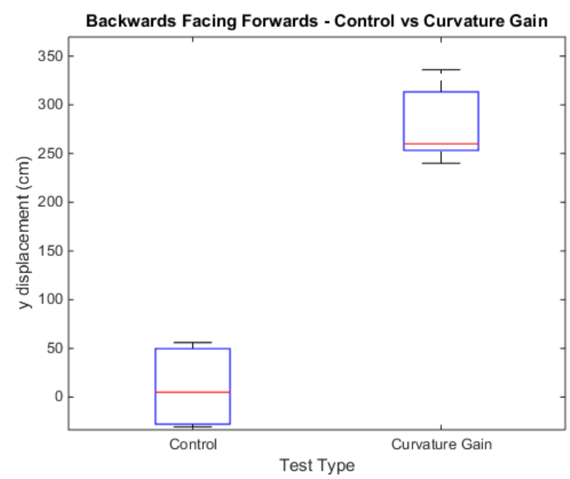

Figure 7: Box Plot of Backwards Facing Forwards Techniques

results, since curvature gain affects the physical path instead of permanently offsetting the user's viewpoint. A one-way ANOVA test was performed with the null hypothesis $H_0 : \mu_1 = \mu_2 = \mu_3 = \mu_4$ with the results seen in Figure 10.

From Table 2, it can be seen that the results are not statistically significant (p-value = 0.1640) thus the null hypothesis cannot be rejected. This confirms that there is not enough evidence to prove there is any difference in deviation from the forwards and backwards locomotion cases. From the figure itself, it can be seen that the tests all have similar results with very similar mean values within a range of 37.8 cm. There appears to be the least deviation in results for forwards walking and walking backwards with occasional backwards looking. It can be concluded that the amount of strafe deviation in the walking path in this experimental setup are not affected by backwards locomotion any differently than forwards locomotion.

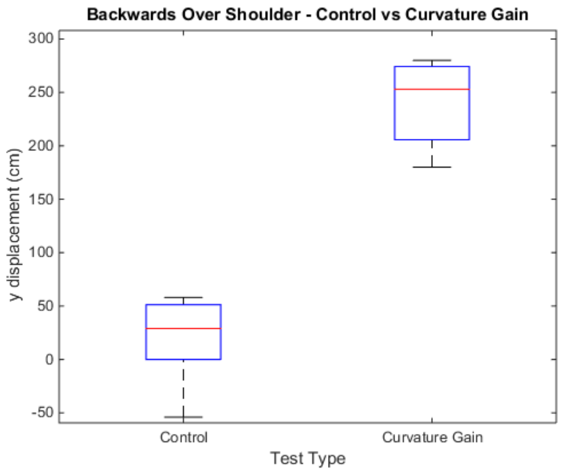

Figure 8: Box Plot of Backwards Over Shoulder Techniques

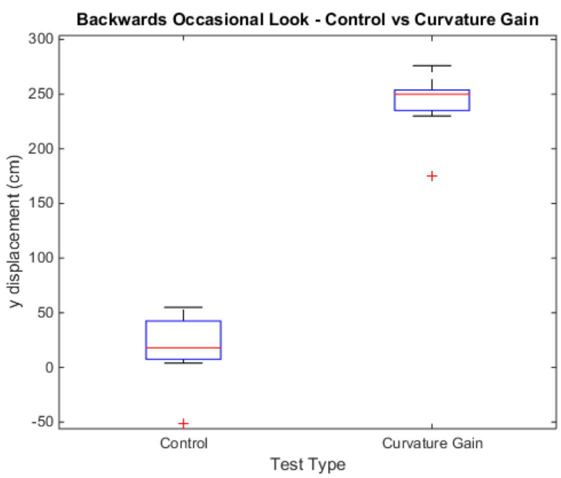

Figure 9: Box Plot of Backwards Occasional Look Techniques

Table 2: One-sided ANOVA Test for Forward and Backwards Redirection Techniques

Source	SS	df	MS	F	Prob >F
Columns	6881.3	3	2293.76	1.86	0.164
Error	29658.6	24	1235.77		
Total	36539.9	27			

5.2 Qualitative

From the survey data collected, none of the users suffered from any severe simulator sickness. Two participants noticed eye strain and slight dizziness after the experiment was completed, which took no more than 20 minutes each. Most of the participants relayed being new to using HMD virtual reality, especially while walking and relayed positive opinions. In contrast, the results relayed that

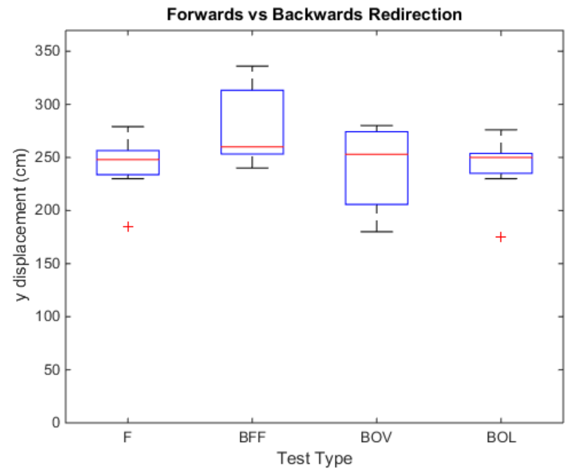

Figure 10: Box Plot of Forwards vs Backwards Redirection Techniques

only 14% of non-control trials allowed the user to deviate from a straight path without noticing unusual or visual shifting effects, most commonly in the third case, when looking over the shoulder and least commonly in forwards redirection. Two popular themes in comments collected by participants were that they noticed the applied shifting because of the gridlines implemented in the virtual environment closer to their feet, and that even though they noticed some form of deviation, when they removed the headset, they were surprised by how much further they had deviated than expected.

6 DISCUSSION

As expected, the effect of curvature gain as a redirection steering technique is significant, but is not significantly altered by changing from forwards to backwards locomotion. Because curvature gain affects the physical pathway of the user instead of gradually offsetting the user's virtual viewpoint, as in pure rotational or translational gain, the path can be followed regardless of the locomotion type. It was noticed that the range of distances deviated is larger in the "backing away" case and "backwards while constantly looking over shoulder" cases. This could possibly be due to the fact that these were the least natural ways of walking, even in control cases. However, the results still show that the amount of variation in all of the backwards cases are much higher than the forwards walking case. The higher variance in backward redirection results shows that while the paths can still be altered, backwards locomotion requires additional tuning unpredictability in human sensitivity to steering. An affecting limitation of the setup that could change the variability is the limited field of view in the HMD. Participants were required to twist their body a full 180°to walk backwards while seeing the goal behind them, whereas in real space, humans are capable of estimating positions of objects from the edge of their peripheral vision.

While the users noticed they were being steered, deviations still occurred. Human susceptibility to accepting and ignoring minor shifts in orientation and position is largely dependent on the amount of concentration that is placed on the shift itself, and it was noted that the virtual environment was very plain with little distraction. The use of a gridded floor was chosen to have the users feel comfortable and well oriented in a virtual space, however this proved to be one more visual aid that allowed them to easily detect shifts. The use of only one single visual element as the goal also gave them the rest of their concentration to focus on noticing possible shifts. By increasing the amount of visual elements, the user has more information to distract them and also allows more rotation gain to be applied as they will turn their heads more.

A mechanism behind the users noticing redirection most often with forwards walking is that backwards locomotion requires more of the user's concentration on balance and allows them to ignore or unconsciously accept small changes in position or orientation. One limitation may have greatly affected the implementation of redirection techniques was the frame rate limitation on the positional tracking mechanism. Because gain values are based on incremental displacements measured by a device that requires both wireless communication and image processing, the low data transfer and update rate of 8-10 Hz forced the steering in translation and rotation to be applied by a larger portion in a less continuous fashion. Finding a more robust method of position tracking that would allow for faster movement updating would greatly help in reducing noticeable shifting effects.

7 FUTURE WORK

The next step to confirm backwards locomotion is not significantly different from forwards walking in regards to steering redirection techniques would be to implement a more complex virtual environment to stop participant from noticing obvious shifting. In these cases, it may be easier to test the effectiveness of pure rotation gain and measure differences in forwards and backwards locomotion.

Further fine tuning is required to measure the sensitivity of humans to the numerical gain values applied, which were calculated based an estimate maximum gain possible from the room size limitations (8m x 5m). More detailed test cases can be developed following the experiments run by [4][5] to test if there are any differences in gain sensitivity during forwards and backwards locomotion, as well as a more robust and calculated relationship between the two numerical gain values applied in curvature gain. Because it was found that users are more careful in backwards locomotion, it is hypothesised that the optimal gain values to reduce noticeability in backwards and forwards locomotion will differ such that higher gains can be applied when walking backwards. This can also largely be used in a more applied case in that backing up from objects usually occurs when correcting movements or moving away from enemies in gaming, creating further methods of distraction from the shifting effect.

Additionally, due to the limited sample size, outliers in the current results may have a larger impact on the results than desired. In the current data set, users were all right handed, mostly male subjects in their 20s and were only steered to their right side. While it was hypothesised that subjects more reliant on their vestibular senses or participants with higher resolutions in their visual acuity may be able to identify the redirection cues more easily, this could not be easily tested due to the limited sample size. Experiments with a greater sample size and with more variation amongst individual users may provide more significant trends for analysis.

8 CONCLUSIONS

After the experiment was conducted to examine differences in redirection techniques in forwards and backwards locomotion, it was found that using the technique of steering was equally effective in all tested cases of walking forwards and backwards. There was no significant difference between distances deviated in all non-control cases using the same amount of curvature gain applied to shift the user's virtual position and orientation. Furthermore, the use of curvature gains allows the users path to be predicted and enforced quite accurately. These results prove that steering as a redirection technique can be used to decrease room size requirements and allow virtual reality environments to expand to much larger spaces than their virtual counterparts, regardless of walking style. It is noted that redirection techniques proved to have less predictable results during backwards locomotion over forwards redirection walking. As such, extra care may be needed when adjusting exact curvature gains for backwards locomotion such that the effects are less noticeable.

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