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# Quick Estimation of Detection Thresholds for Redirected Walking with Method of Adjustment

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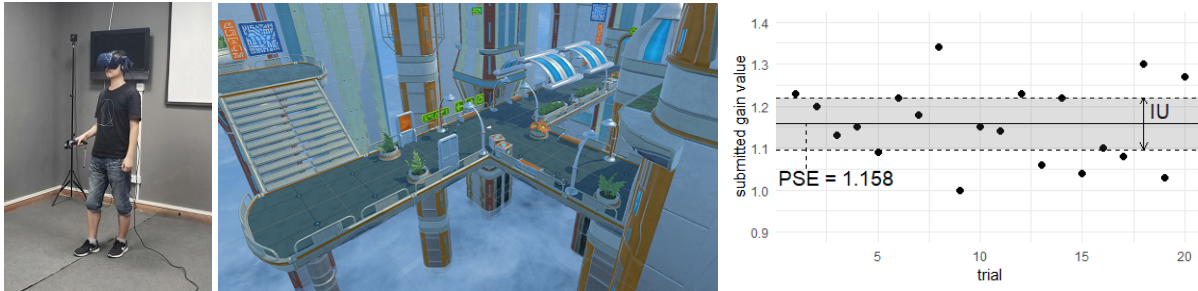


Figure 1: (left) A user completed the experiments with an HMD and a controller. (center) The virtual street used for walking in our experiments. (right) An example of the distribution of gain values (represented by the dots) submitted by a user tested with MoA.

## ABSTRACT

A method that allows quick estimation of Redirection Detection Thresholds (RDTs) is not only useful for identifying factors that contribute to the detection of redirections, but can also provide timely inputs for personalized redirected walking control. In aim to achieve quick RDT estimation, we opted for a classical psychophysical method - the Method of Adjustment (MoA), and compared it against commonly used method for RDT estimation (i.e. MCS-2AFC) to see their difference. Preliminary results show that MoA allows to save about 33% experiment time when compared with MCS-2AFC while getting overall similar RDT estimations on the same population.

**Keywords:** Redirected Walking, Detection Threshold, Method of Adjustment.

**Index Terms:** H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities;

## 1 INTRODUCTION

Redirected walking has been actively developed and pushed forward by joint force from virtual reality and science of perception. One of the main questions on redirected walking is - how much can we redirect the users before they notice the gains? To answer this question, Redirection Detection Thresholds (RDTs) are defined to represent the limits of undetectable gains and serve as important input parameters for redirected walking algorithms. In fact, the estimation of RDTs is more complex than other perception-related tasks (e.g. size or color discrimination) since the stimuli come from multiple (visual, vestibular and proprioceptive) channels instead of one, so traditional psychophysical methods need to be properly adapted in order to take account of this complexity.

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Since the first comprehensive study on RDT estimation by Steinicke et al. [7] with the Method of Constant Stimuli combined with a Two-Alternative Forced Choice task (MCS-2AFC), many follow-up studies repeated the measurement of RDTs with the same estimation method, but under different experimental conditions [5].

The advantage of using MCS as sampling method is that it is generally believed to be more reliable than other classical psychophysical methods by providing a complete picture of users' psychometric functions. However, the high time cost of MCS makes it difficult to scale up the experiments by involving more subjects or to test the influence of different factors on RDTs. Second, it is difficult, even impossible to collect data from people having trouble with long-exposure VR experience (i.e. cybersickness).

In fact, some adaptive sampling methods have also been used for RDT estimation. For example, Razzaque [6] conducted several initial experiments on scene rotation detection with adaptive 2-track staircase methods. Grechkin et al. [2] studied the interaction between translation and curvature gains by using Green's maximum likelihood procedure. Nguyen et al. [4] used a two interleaved 2AFC task combined with a three-down/one-up staircase method with fixed step size for left and right directions, etc. Adaptive methods are surely more time efficient than MCS as they require less trials, but it is unclear how to make design choice for adaptive methods with numerous variants and parameters to set.

As a consequence, we opt for a third class of classical psychophysical method - the Method of Adjustment (MoA) as an alternative of MCS and adaptive methods in order to make quick assessment of RDTs for redirected walking. The reason for choosing MoA is that it is intuitively appealing, easy to set up, and in general it requires much fewer test trials than other methods. In practice, a rough estimation of RDTs is sufficient to describe a user's "profile" (e.g. sensitive or insensitive) regarding gain detection for calibration purpose.

## 2 METHOD OF ADJUSTMENT

In existing literature, RDTs were mostly reported in form of a tuple of lower and upper detection limits. This form is intuitive as it directly shows the usable interval of undetectable gains for the redirection controller. However, here we took a different representation of the threshold: a combination of the Point of Subjective Equal-

ity (PSE) and the Interval of Uncertainty (IU) [1] which could be written in form of  $[PSE-IU/2, PSE+IU/2]$  for the following reasons: the PSE is an indication of user's (positive or negative) bias on gain perception (more sensitive to larger or smaller gains), while the IU is another important factor characterizing user's gain detection ability, for example, a user with high IU provides more room for maneuver to the redirection system than those who have lower ones. MCS-2AFC and MoA employ very different ways to compute PSE and IU. The former gets PSE and IU indirectly from the fitted psychometric curve. We used the same sigmoid function as described in [7]:

$$p = f(x) = \frac{1}{1 + e^{ax+b}} \quad (1)$$

Here  $x$  is the applied redirection gain and  $p$  is the probability that the user considers the amplitude of real locomotion to be greater than the virtual counterpart. This probability is computed by counting the "real is greater" trials divided by the total trial number per gain value.  $a$  and  $b$  are parameters setting by curve fitting.

The PSE corresponds to the gain value of  $f^{-1}(0.5)$ . IU is bounded by a lower detection threshold  $f^{-1}(0.25)$  and an upper bound  $f^{-1}(0.75)$ , which is two times the Just Noticeable Difference (JND). Here are the equations for computing PSE (2) and IU (3):

$$PSE = f^{-1}(0.5) = -\frac{b}{a} \quad (2)$$

$$IU = f^{-1}(0.75) - f^{-1}(0.25) = 2 \cdot JND = -\frac{2 \cdot \ln 3}{a} \quad (3)$$

Unlike MCS-2AFC, MoA directly asks users to manually adjust the magnitude of redirection gain from a random starting value till no difference can be detected between visual and non-visual stimuli.

MoA contains equal number of ascending and descending trials that are tested alternatively in order to reduce estimation error. Fig. 1 right shows an example of 20 trials from a subject with illustration of corresponding PSE and IU. The computation of PSE and IU (Equation 4) for MoA is described as follows:

$$PSE = \mu(g) \quad ; \quad IU = 2 \cdot JND = 2 \cdot z(0.75) \cdot \sigma(g) \quad (4)$$

$g$  is the gain value submitted at the end of each trial,  $\mu$  and  $\sigma$  are the mean and standard deviation of submitted gain values. JND is given by multiplying the standard deviation of PSEs by a z score of probability of 0.75 (about 0.6745) [3].

### 3 EXPERIMENT OVERVIEW

First, we assessed users' RDTs for different types of gains - translation, rotation and curvature using MCS-2AFC, which is known to be robust against various bias. Second, we used the found gains values as baseline for the comparison with an MoA approach defined above.

In MCS-2AFC experiment, we followed similar procedure of Steinicke et al.'s previous experiment [7]. For each trial, the subject began by standing on the starting point facing a fixed direction, then walked (rotated) towards the target (a green floating sphere) till it changed color. After each trial, a question was shown in a pop-up window that allowed the subject to make the forced choice. For the curvature sub-experiment, we used a small step ( $5^\circ$  interval) at gains in range  $[0^\circ, 20^\circ]$  and a bigger one ( $10^\circ$ ) for gains larger than  $20^\circ$ . We also measured left and right turns separately so each angle was tested five times. This experiment differs from the one of Steinicke et al. on two aspects: First, since the physical workspace available was quite small, in the translation sub-experiment we fixed the virtual travel distance to be 2.5m and the real walking distance varied according to the gain value. No "redirection-free" pre-walking was possible due to the space limitation. Second, Steinicke et al.

got estimates of RDTs from the average samples of all subjects instead of fitting individual psychometric functions. Here we fitted the psychometric curve for each subject so we can get a per-subject RDT estimation.

In MoA experiment, subjects were not constrained in a routine starting position and walking path as imposed by MCS-2AFC. The task for the subjects to accomplish was to adjust gain values until they can no longer feel the discrepancy between the virtual and real paths. At the beginning of each trial, the subject was given a random starting gain value and a handheld controller with buttons to adjust the gain in two directions. The subject can adopt fine tuning by clicking the "up" or "down" button, or apply quick modifications by pressing and holding the same buttons. There was no imposed starting location for all trials, which means the participants can start the next trial immediately after each gain submission. For the translation and rotation sub-experiments, ascending ( $g_{init} < 1$ ) and descending ( $g_{init} > 1$ ) trials were presented alternatively, where  $g_{init}$  was the starting gain value. For the curvature sub-experiment, we did not force left-right alternative distribution of the starting gain  $g_{init}$  to prevent learning effect. In all sub-experiments,  $g_{init}$  was a random value chosen to be away from the neutral zone and the lower or upper limits of gains. There was no time limit or predefined path for all subjects during the experiment. They can submit the final choice for a trial by clicking a trigger button on a controller.

Those experiments were carried out on 24 subjects in a lab room with a standard commercial VR setup (HTC Vive Pro, see Fig. 1 left). Tracking zone is a rectangle of  $3m \times 4m$  with a safety margin of 0.3m to the walls. The virtual scene was a futuristic city rendered by Unity 3D (see Fig. 1 center).

### 4 CONCLUSION

With only 20 trials per subjects, MoA provided similar RDT estimates with MCS-2AFC and allowed to save about 33% experiment time. So MoA is a good option to quickly assess averaged RDTs for a given population in pre-walking calibration or to evaluate the impact of different factors on RDTs in an affordable way. In the future, comparisons between MoA and popular adaptive methods can also be conducted in order to provide more useful information about the impacts of methodology on RDTs.

### ACKNOWLEDGMENTS

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