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Hand choice in virtual reality: Effects of target position and expected reward

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Abstract

Contemporary virtual reality (VR) systems enable continuous measurement of hand and arm movements within controlled environments. Previous investigations have focused primarily on movement execution, with less attention to action selection. We test whether established principles of hand choice extend to immersive VR. Participants reach to virtual targets on either side of the body midline. The point of subjective equality (PSE) represents the target location where either hand is equally likely to be used. Experiment 1 shows that target position systematically influences hand choice and decision time. The PSE is near the body midline, where predicted biomechanical and energetic costs are comparable between hands, but shifts slightly into left space at the group level, indicating a modest preference for the dominant right hand. Participants take longer to initiate movements near the PSE, but only when free to choose which hand to use. These findings reproduce established non-VR results. Experiment 2 shows that manipulating game points systematically alters hand choice. When high-value game points favour the non-dominant hand, participants use that hand more often, shifting the PSE. This effect persists in participants who do not explicitly report awareness of the manipulation. Together, these results show that target position and reward structure predictably influence hand choice in VR, consistent with a utility-based account in which actions are evaluated according to predicted costs and expected benefits. They demonstrate that key principles of hand choice extend to immersive VR, providing a foundation for developing rehabilitation games aimed at encouraging voluntary use of an impaired hand.

Keywords: Virtual reality; Hand choice; Action selection; Reward; Sensorimotor control.

Introduction

Extended reality technologies like immersive virtual reality (VR) offer new opportunities for movement rehabilitation. VR systems can control the opportunities for action, measure the movements that follow, and adapt the task in response. Targets can be placed precisely in space, given specific properties, and presented with controlled timing. Hand, arm, and head movements can be tracked continuously, allowing objective measurement of which limbs are used and how movements are performed. This information can then be used to shape future action opportunities, modifying target properties, criteria for success, performance feedback; or the rewards assigned to specific actions.

This potential is often discussed in terms of movement practice. VR can support high numbers of task-specific, engaging, and progressively challenging actions (Levin et al. 2015; Maier et al. 2019). Less attention has been given to the possibility that VR-based applications could also be used to retrain upstream processes involved in action planning and selection. This may be important for upper-limb rehabilitation after stroke. Many patients avoid using the affected arm, even when some capacity remains (Taub et al. 2006; Rand and Eng 2012; Bailey et al. 2015). Rehabilitation tools that increase the likelihood of affected-hand use may therefore support recovery not only by increasing practice with the affected limb, but also by repeatedly engaging the processes involved in action planning and selection, including hand choice: deciding which hand is used to perform an action.

Action selection can be framed as a utility-based process. Candidate actions are assigned value according to their expected benefits and predicted costs (Rigoux and Guigon 2012; Shadmehr et al. 2016). Choices tend to favour higher-utility actions: those that achieve task goals effectively while minimising costs. Sensorimotor accounts provide a compatible mechanistic view of this process. According to the *Affordance Competition Hypothesis*, potential actions are represented in parallel within cortical systems involved in action planning and control, where they compete for selection (Cisek 2007; Cisek and Kalaska 2010). The mechanisms that specify possible actions also provide a substrate for deciding between them, allowing predicted motor costs and expected outcomes to directly influence action choice.

Results from studies of hand choice are consistent with this framework. When people are free to choose which hand to use, their choices appear to reflect the relative utility of competing hand-specific actions (Stoloff et al. 2011; Schweighofer et al. 2015; Valyear et al. 2019) and brain areas important for action planning and control are preferentially involved (Fitzpatrick et al. 2019). One key determinant is the predicted biomechanical and energetic costs associated with competing movements. Reaching in different directions imposes different costs related to the inertial properties of the arm (Gordon et al. 1994; Carey and Otto-de Haart 2001), and under conditions of free choice, people appear to respect these constraints both when choosing how to move the arm (Sabes and Jordan 1997; Cos et al. 2011; Dounskaia et al. 2011) and when choosing which hand to use (Schweighofer et al. 2015). Near the body midline, the costs of using either hand are more closely matched, and either hand is selected with similar probability. At more lateral positions, the ipsilateral hand is favoured and selected more often.

This spatial gradient is also evident in movement-initiation times. When participants are free to choose which hand to use, movements are initiated more slowly to targets near the body midline than to more lateral targets (Oliveira et al. 2010; Stoloff et al. 2011; Fitzpatrick et al. 2019; Valyear et al. 2019; Fitzpatrick et al. 2022). This slowing is not observed when hand use is predetermined (Oliveira et al. 2010). Similar timing costs are observed in other action-selection contexts, when the mapping between stimulus and action is ambiguous, such as when object orientation does not clearly favour one wrist posture over another (Johnson et al. 2000; Wood and Goodale 2011). Thus, time to movement onset provides a behavioural index of competition during action selection: movements are initiated more quickly when the relative costs and expected outcomes clearly favour one candidate action, and more slowly when competing actions are more closely balanced.

Handedness can be understood within this framework as a persistent asymmetry in the expected utility of the two hands, shaped by biological predisposition (Annett 2000; de Kovel et al. 2019), lifetime experience (Llaurens et al. 2009), and task-specific skill (Coelho et al. 2013; Przybyla et al. 2013). The dominant hand may be more often selected because it is expected to perform actions more effectively. Consistent with this interpretation, hand-selection patterns are linked to intermanual differences in movement kinematics and task performance (Kim et al. 2011; Coelho et al. 2013; Przybyla et al. 2013), and dominant-hand use increases when actions place greater demands on skill, precision, or coordination (Stins et al. 2001; Bryden and Huszczynski 2011)

Effects of expected reward follow directly from this framework. If the utility assigned to a hand-specific action increases with its expected benefit, then increasing the reward, value, or probability of success associated with one hand should increase the likelihood that this hand is selected. Stoloff et al. (2011) provide evidence consistent with this principle. Using a free-choice reaching task, they manipulated limb-dependent reinforcement by increasing the probability of success for the non-dominant

hand, decreasing the probability of success for the dominant hand, or combining both manipulations. Non-dominant-hand use was increased, especially for targets positioned near the body midline, where the biomechanical and energetic costs of using either hand are similar. These shifts in hand choice occurred with limited explicit awareness and were captured by a reinforcement-learning model in which hand-choice preferences were updated by recent success and failure.

The present study asks whether these same principles operate in immersive VR. We used an established paradigm in which targets appear to the left and right of the participant's body midline, and participants are free to choose which hand to use to reach to intercept them. In Experiment 1, we tested whether two empirical markers repeatedly observed in previous conventional reaching studies are also observed in VR. First, when reaching to targets near the body midline, either hand should be selected with similar probability, whereas at more lateral positions, the ipsilateral hand should be selected more often. In right-handed participants, this pattern should produce a point of subjective equality (PSE)—the location at which either hand is selected equally often—that falls slightly left of the midline, reflecting greater use of the dominant right hand. Second, movements should be initiated more slowly near the PSE than for more lateral targets, and this slowing should be specific to conditions in which participants are free to choose which hand to use.

In Experiment 2, we tested whether game points can shift hand choice by changing expected reward. Participants completed a free-choice reaching task with the same basic structure as Experiment 1, but we manipulated the point schedule so that high-point rewards were more likely following non-dominant-hand use. According to the utility-based framework introduced above, increasing the expected reward associated with one hand should increase the relative utility of actions performed with that hand. Biasing game points in favour of the non-dominant hand should therefore shift hand choice toward the non-dominant hand, and this should be expressed as a corresponding shift in the PSE.

Demonstrating that established cost- and reward-related principles of hand choice operate in VR is a necessary step if these principles are to be used in designing VR-based tools for rehabilitation. If hand choice in VR can be biased by target location and reward structure, then rehabilitation games could exploit these parameters to increase the likelihood that patients select and use the hand targeted for rehabilitation. Such tools could therefore increase practice with the targeted hand while naturally and repeatedly engaging the planning and selection processes that underpin hand choice.

General methods

Participants and ethics

Participants in both experiments were healthy adults with normal or corrected-to-normal vision and no self-reported neurological, psychiatric, or upper-limb musculoskeletal conditions. Participants were naïve to the aims of the study. All procedures were approved by the Bangor University School of Psychology Research Ethics Committee, and all participants provided written informed consent before taking part. Participants received course credit as compensation.

Handedness was assessed by self-report using the question: “Do you consider yourself left-handed, right-handed, or ambidextrous?” At the end of each session, participants were asked whether they experienced any adverse effects, including cybersickness.

Apparatus, task environment, and spatial conventions

In both experiments, participants performed seated reaching tasks in immersive VR. The tasks were presented using a Meta Quest 3 headset (2064 × 2208 pixels/eye, 120 Hz refresh rate; 110° horizontal field of view). Targets were red spheres, 10 cm in diameter, presented at locations defined relative to the participant’s body midline, with negative values corresponding to left space and positive values to right space. The two experiments differed in tracking method, target range, feedback, and task structure; these details are described separately for each experiment.

General task structure and calibration

Before testing, participants donned the headset, adjusted it for comfort, and re-centred their position so that the virtual midline aligned with their body midline. The virtual workspace was calibrated so that targets were comfortably reachable without trunk movement. In both experiments, participants extended their dominant arm directly in front of the body to a comfortable maximum reach. This reach-based calibration translated the target arc so that targets were positioned within each participant’s comfortable forward reaching range. Additional experiment-specific calibration procedures are described below.

Hand choice and PSE estimation

Hand choice was modelled using participant-level logistic functions relating hand choice to target position. Hand choice was coded as a binary outcome and modelled using a binomial generalised linear model with a logit link. For right-handed participants, right-hand choices were coded as 1 and left-hand choices as 0. For left-handed participants in Experiment 2, data were mirror-reversed before analysis so that dominant/non-dominant hand use was coded consistently across participants.

The model estimates the probability P of a dominant-hand choice at target angle θ as:

$$logit[P(\,Dominant \mid \theta\,)] = \beta 0 + \beta 1\theta$$

From each participant's fitted model, we derived the point of subjective equality (PSE), defined as the target location at which the model predicts equal probability of using either hand. For this linear-in-angle logistic model, the 50% crossing has a simple closed-form:

$$PSE = -\beta 0/\beta 1$$

95% confidence intervals were computed for each PSE using the model's coefficient covariance matrix (delta method). Goodness-of-fit was evaluated separately for each participant's logistic model using McFadden's pseudo-R^2, and then summarised at the group level.

Statistical reporting

Statistical significance was evaluated at $p < 0.05$. Effect sizes and 95% confidence intervals are reported where appropriate. Post-hoc pairwise comparisons were corrected for multiple comparisons using the Šídák method. Both uncorrected and corrected (p_{adj}) p-values are reported.

For non-significant results central to the interpretation, complementary Bayesian hypothesis tests were conducted in JASP using default settings (JASP Team 2025). For Bayesian t-tests, Bayes factors are reported as BF_{10} calculated with a Cauchy prior width of r = 0.707. BF_{10} quantifies evidence for the alternative hypothesis relative to the null; values below 1/3 are interpreted as moderate evidence in favour of the null hypothesis. For Bayesian ANOVAs, inclusion Bayes factors are reported as BF_{Incl}. BF_{Incl} quantifies evidence for including an effect or interaction relative to matched models excluding that term; values below 1/3 indicate moderate evidence against inclusion.

Data inclusion and exclusions

Unless otherwise stated, analyses retained all valid task trials and did not exclude trials as statistical outliers. Experiment-specific participant exclusions and any additional trial-level exclusions are reported in the relevant experiment.

Experiment 1

Methods

Participants

Twenty healthy adults took part in Experiment 1 (6 male, 14 female; mean age = 28.1 ± 6.64 years; range: 23–51 years). All participants identified as right-handed. The session lasted approximately one hour. No participants withdrew from the study, and no adverse effects were reported.

Setup and materials

Participants were seated in a chair within a 2 x 2m clear space. The task was performed in VR using a Meta Quest 3 headset (2064 x 2208 pixels/eye, 120Hz refresh rate; 110° horizontal field of view) operated in PC-tethered mode via a 5m Link cable. Hand movements were tracked using the Meta Touch Plus controllers under consistent fluorescent lighting. The experiment was programmed in Unity (version 2023.2.11f1; Universal Render Pipeline) using the FSM Playmaker package (version 1.98) and Meta XR SDK (version 62.0.0).

Targets were red spheres (10 cm diameter), positioned at 11 locations spanning -80° to +80° relative to the participant's body midline (–80°, –67°, –53°, –39°, –18°, 0°, 18°, 39°, 53°, 67°, 80°), indexed left-to-right as targets 1 – 11. The target arrangement modelled previous work (Oliveira et al. 2010; Stoloff et al. 2011; Valyear et al. 2019), with the addition of a veridical centre target at 0° (Fig. 1A).

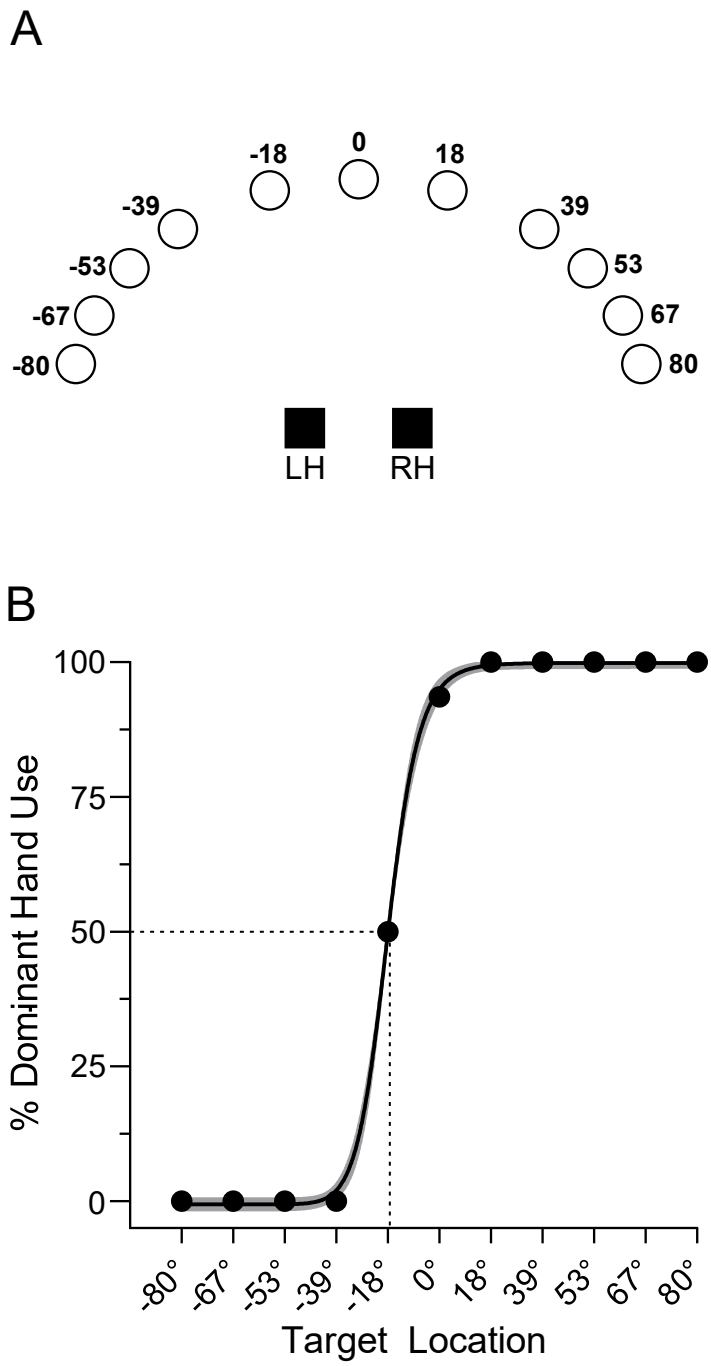


Figure 1. Target layout and example point of subjective equality (PSE) estimation. A: Eleven targets were positioned from -80° to +80° relative to body midline. Black squares indicate the left- and right-hand home positions (LH and RH). **B:** Example logistic fit for a single participant. Black circles show observed percentage dominant-hand use at each target location. The solid curve shows the fitted psychometric function. Dashed lines identify the target location at which predicted dominant-hand use was 50%, defined as the PSE.

Prior to the main task, a calibration was performed to ensure that all targets were comfortably reachable without trunk movement; the calibration procedure shifted the target arc forward or backward based on each participant's maximum right-arm reach.

At trial onset, participants positioned both controllers within two 'home position' cubes (5 x 5 x 5 cm) located symmetrically to the left and right of midline. A 20 x 20 cm fixation cross was displayed centrally when no target was visible. Participants were asked to focus on this cross whenever it was visible.

Procedure

Before headset fitting, participants' familiarity with VR was assessed verbally, and a 30-second demonstration video of the task was shown. Participants then donned the headset, adjusted it for comfort, and re-centred their position in the virtual space such that the virtual midline aligned to their body midline. The experimenter then initiated the calibration for arm length by pressing a key while the participant extended their dominant arm fully forward. The entire target arc was translated accordingly.

Each trial began when both controllers were placed in the home positions. After a fixed delay of 1500 ms, the fixation cross disappeared and a single target appeared at one of 11 possible positions. Target locations were randomly selected with equal probability. Before onset, target position was jittered by up to ±1.5 cm in both the horizontal and vertical plane.

A successful hit changed the target's colour from red to blue, and the target then disappeared. Regardless of outcome (hit or no hit), the target disappeared after 1500 ms, and participants returned both controllers to the home positions, ready for the next trial.

There were two task conditions: Choice and Instructed. In the Choice condition, participants were free to choose which hand to use on each trial. In the Instructed condition, hand use was prescribed before the first trial began. Each condition was presented in a separate block comprising 352 trials, with 32 trials per target location. The two condition blocks were separated by a 5-minute rest period, and their order was counterbalanced across participants.

Within the Instructed block, trials were divided into two single-hand sub-blocks. At the outset of each sub-block, participants were instructed to complete all trials using only the right hand or only the left hand. Thus, half of the trials at each target location were completed with each hand. Sub-block order was counterbalanced across participants.

Dependent measures and analyses

Hand choice. Hand choice and PSEs were estimated as described in General methods. For Experiment 1, PSEs were computed separately for each participant using Choice trials only, as illustrated in Fig. 1B. A two-tailed one-sample t-test evaluated whether the group-level PSE differed significantly from zero.

The reliability of PSE estimates was assessed using two split-half procedures. First, trials were split into odd and even trials; second, trials were split into first and second halves according to trial order. For each split, PSEs were re-estimated separately for each participant, and the paired PSE estimates were correlated across participants. Split-half reliability was summarised using Spearman's ρ and Spearman-Brown corrected reliability.

Response times. Response times (RTs; i.e., time-to-movement onset) were defined as the time from target onset to the first departure of either controller from its home position.

Our primary interest was to evaluate whether RTs in the Choice condition are prolonged near the PSE. This analysis follows Oliveira et al. (2010), who show that the PSE defines a region of space associated with greater choice costs: RTs are longer for reaches to targets near the PSE than to more lateralised targets, but only when participants are free to choose which hand to use. When hand use is predetermined, as in our Instructed condition, this difference is not observed. Thus, increased RTs for reaches to targets near the PSE are taken as evidence of a competitive process, reflecting additional time required to decide which hand to use when the biomechanical and energetic costs of using either hand are comparable.

For each participant, we therefore defined two target regions: PSE, comprising the two targets that bounded the participant's PSE, and Extreme, comprising the two most lateral targets at ±80°. RTs were analysed using a 2 × 2 repeated-measures ANOVA with Region (PSE, Extreme) and Task (Choice, Instructed) as within-participant factors.

Results and discussion

Hand choice reflects target position and dominant-hand preference

Hand choice varies with target position. Responses to more lateralised targets involve more frequent use of the hand ipsilateral to the target location (Fig. 2A). Participant-level logistic models provide good fits to the data, with a mean McFadden's pseudo-R^2 of 0.84 ± 0.09.

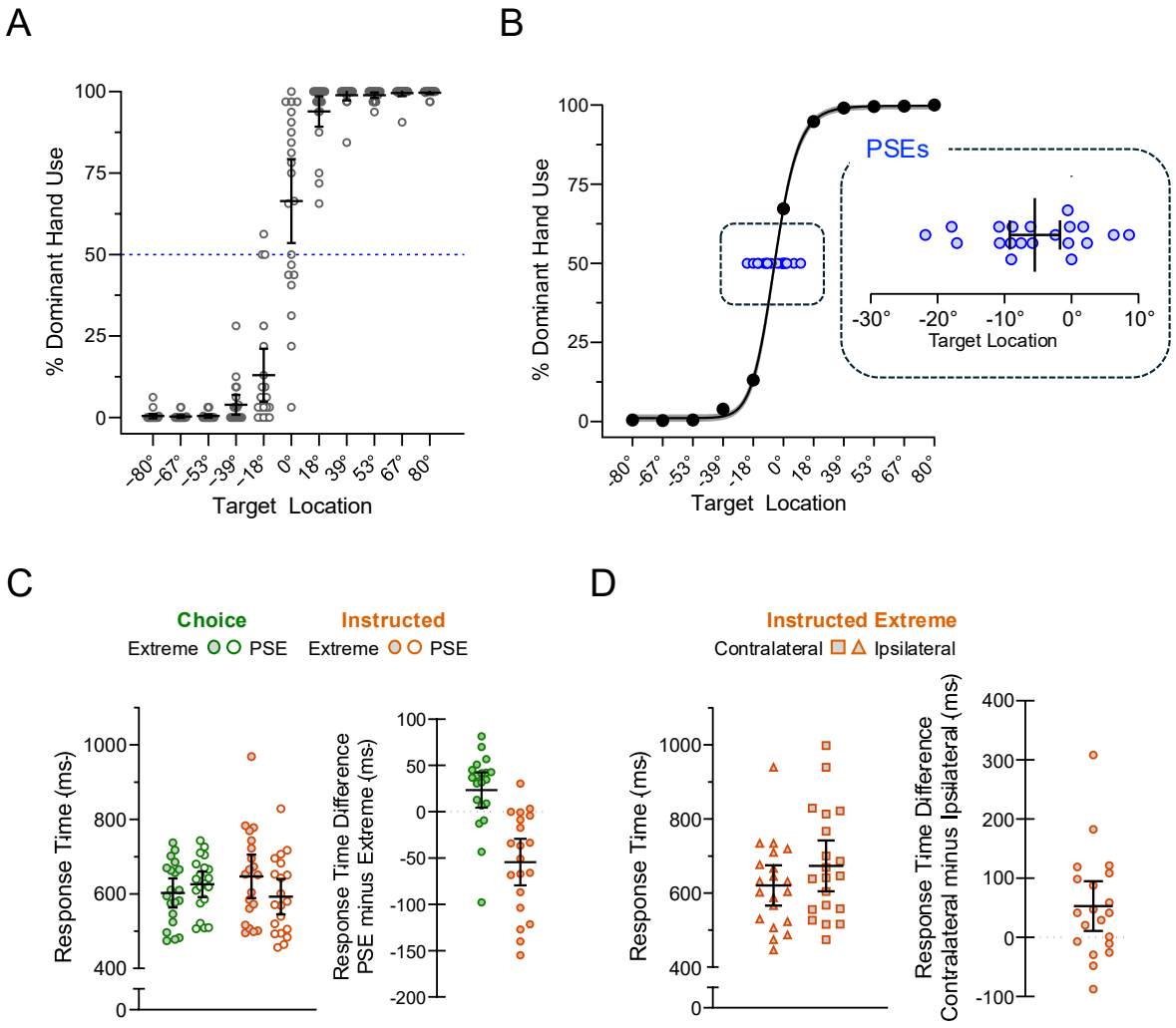


Figure 2. Hand choice behaviour and response times. A: Group-level dominant hand use in the Choice condition across target locations. Grey points show individual participant values. Error bars show group means ± 95% CIs. The dashed line indicates 50% dominant-hand use. **B:** Group-level psychometric function for dominant-hand use across target locations. Blue circles show individual PSE values. Inset shows the distribution of individual PSE estimates. The dashed vertical line indicates the midline. **C:** Response times in the Choice and Instructed conditions, shown separately for reaches to extreme targets (±80°) and targets surrounding the PSE. The right panel shows PSE-minus-Extreme difference scores for Choice (green) and Instructed (orange) conditions, respectively. Error bars show means ± 95% CIs. **D:** Response times for contralateral (square) and ipsilateral (triangle) reaches to extreme targets in the Instructed condition. The right panel shows contralateral-minus-ipsilateral difference scores. Error bars show means ± 95% CIs.

PSE estimates also show good split-half reliability. Odd-even split-half estimates correlate strongly across participants ($\rho = 0.90$, $p < 0.001$, with a Spearman-Brown corrected reliability of 0.95). Estimates from the first and second halves of the task block show similar reliability ($\rho = 0.80$, $p < 0.001$, with a Spearman-Brown corrected reliability of 0.89).

The group-level PSE is systematically shifted leftward of centre (M = -5.47°, 95% CI [-9.22°, -1.72°]; Fig. 2B). A two-tailed one-sample t-test confirms that this shift differs significantly from zero, ($t(19) = 3.05$, $p = 0.007$; $d = -0.68$, 95% CI [-1.16, -0.19]). Thus, the PSE falls near the body midline but, at the group-level, is shifted into left space, consistent with a preference for use of the dominant right hand. These findings show that hand choice in VR reproduces the characteristic spatial gradient observed in conventional reaching studies using similar experimental paradigms (Oliveira et al. 2010; Stoloff et al. 2011; Valyear et al. 2019).

Choosing between hands takes longer near the PSE

RTs show the expected choice-specific pattern: time-to-movement onset is prolonged near the PSE when participants are free to choose which hand to use. ANOVA results reveal a significant Region × Task interaction ($F(1, 19) = 36.32$, $p < 0.0001$; $\eta^2p = 0.657$, 95% CI [0.358, 0.800]) (Fig. 2C). There is no reliable main effect of Region ($F(1, 19) = 3.35$, $p = 0.082$; $\eta^2p = 0.150$, 95% CI [0, 0.426]), or Task ($F(1, 19) = 0.20$, $p = 0.656$; $\eta^2p = 0.011$, 95% CI [0, 0.219]).

Follow-up comparisons clarify the nature of this interaction. In the Choice condition, RTs are increased for targets near the PSE compared to targets at the extreme lateral positions ($t(19) = 2.56$, $p = 0.038$; $M_{diff} = 23.37$ ms, 95% CI [1.21, 45.53]). In contrast, the Instructed condition shows the opposite pattern: RTs are decreased near the PSE compared to the extreme lateral positions ($t(19) = 5.96$, $p < 0.0001$; $M_{diff} = -54.46$ ms, 95% CI [-76.62, -32.29]).

Thus, in the Choice condition, participants take more time to initiate reaches to targets near the PSE. This reproduces a key behavioural signature consistently observed in real-world experiments (Oliveira et al. 2010; Stoloff et al. 2011; Fitzpatrick et al. 2019; Valyear et al. 2019; Fitzpatrick et al. 2022) and supports the interpretation that hand choice in VR also involves increased decision costs when competing hand-specific actions are more closely balanced—i.e., intermanual biomechanical and energetic demands are comparable.

The Instructed condition shows the opposite pattern: RTs are reduced near the PSE compared to extreme lateral targets. This reversal mirrors the results from Oliveira et al. (2010) who report the same pattern when hand use is predetermined. They suggest that this effect may reflect an attentional strategy in which participants focus attention on the centre of the target array, minimising the average distance between their attentional focus and possible target locations.

Here, we consider a second explanation. In the Instructed condition, half of the reaches to extreme lateral targets require contralateral, cross-body movements. These movements are biomechanically and energetically more costly than ipsilateral reaches (Gordon et al. 1994; Schweighofer et al. 2015), consistent with the observation that they are rarely selected when participants are free to choose which hand to use. Similarly, they require longer duration and more complex movements, which can increase the time needed to prepare an action (Klatzky et al. 1995; Valyear et al. 2011). Forcing participants to make these inefficient and otherwise less preferred contralateral reaches may be driving up RTs.

Consistent with this possibility, RTs to extreme targets in the Instructed condition are reliably increased when reaches are made with the contralateral versus ipsilateral hand ($t(19) = 2.64$, $p = 0.016$; $d_z = 0.59$, 95% CI [0.11, 1.06]; $M_{diff} = 52.88$ ms, 95% CI [10.96, 94.80]; Fig. 2D). Likewise, after removing contralateral reaches to extreme lateral targets from the Instructed condition, the RT difference between PSE and Extreme regions is no longer statistically reliable ($t(19) = 1.68$, $p = 0.109$; $dz = -0.38$, 95% CI [-0.83, 0.08]]; $M_{diff} = -26.09$ ms, 95% CI [-58.59, 6.41]; $BF_{10} = 0.77$). These results suggest that the reversed pattern of RT effects in the Instructed condition is at least partly attributable to the added demands of preparing more complex and energetically costly cross-body movements to targets at far lateral positions and, perhaps also, the need to override the normally preferred ipsilateral response.

Experiment 2

Experiment 2 tests whether manipulating game points can shift hand choice. Using the same basic task structure as Experiment 1, we manipulate the point schedule so that high-point rewards are more likely when intercepting targets using the non-dominant hand. According to the utility-based framework, biasing game points in favour of the non-dominant hand should increase the relative utility of actions performed with that hand. Non-dominant-hand use should therefore increase, and this should be expressed as a corresponding shift in the PSE.

The experiment uses two distinct point schedules (Fig. 3). In the Balanced schedule, the probability of receiving high-value points is equivalent for the two hands. The likelihood of obtaining high-point rewards is balanced. In the Boost schedule, high-value points are more likely for non-dominant-hand reaches and less likely for dominant-hand reaches. The likelihood of obtaining high-point rewards is increased—‘Boosted’—for the non-dominant hand.

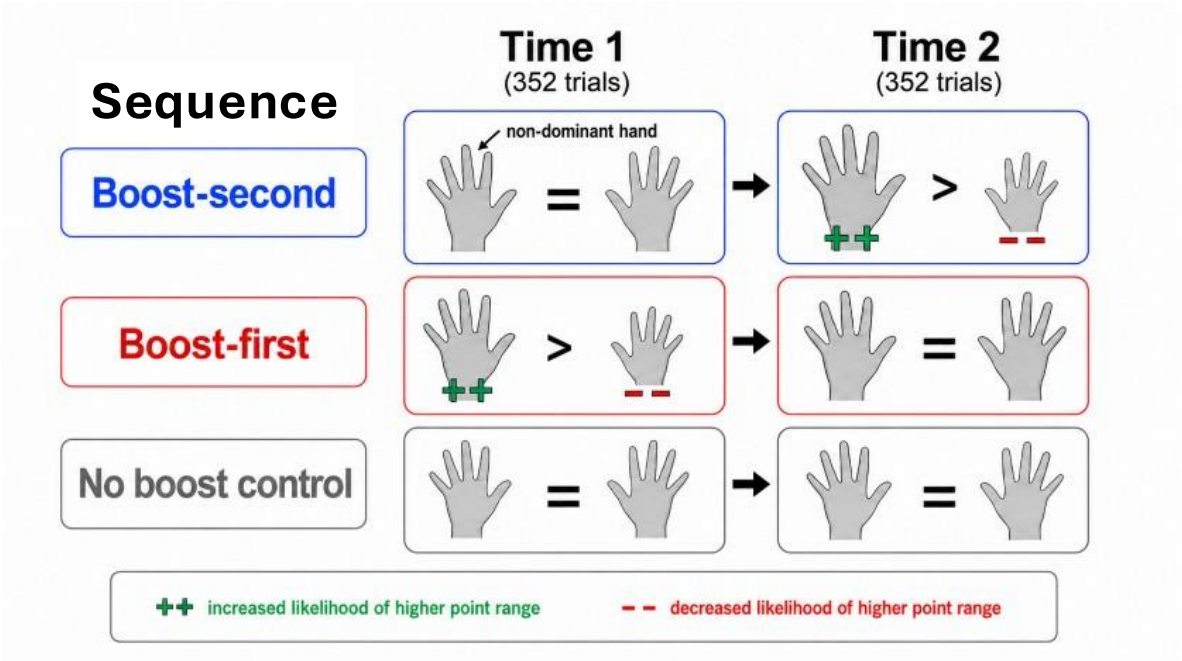


Figure 3. Sequence schematic. Schematic of the point-schedule sequences across both timepoints (Time 1 and Time 2). In the Balanced blocks, both hands had the same likelihood of receiving more points. In Boost blocks, the non-dominant hand had an increased likelihood of receiving more points, whereas the dominant hand had a decreased likelihood of receiving more points. The Boost-second group completed a Balanced block followed by a Boost block. The Boost-first group completed a Boost block followed by a Balanced block. The No boost control group completed Balanced blocks at both timepoints. Green plus and red minus symbols indicate increased and decreased likelihood of receiving more points, respectively.

To test for an effect of the Boost schedule, and to separate this from possible order- or time-related changes, participants are assigned to one of three Sequence groups: Boost-second, Boost-first, or No boost control. In the Boost-second Sequence, the Boost schedule is presented in the second block; in the Boost-first Sequence, it is presented in the first block. Together these conditions allow us to evaluate whether the Boost effect depends on block order. In the No boost control Sequence, both blocks comprise the Balanced point schedule, allowing us to evaluate the stability of hand choice over time when expected reward is held constant and balanced between hands.

Methods

Participants

One hundred and twenty healthy adults took part in Experiment 2 and were assigned to one of three Sequence groups (Fig. 3). Three participants were excluded before analysis: two from the Boost-second group because their calculated PSE fell outside the target range, and one from the No boost control group because of missing data. The final sample therefore comprised 117 participants:

- Boost-second: n = 38; 13 male, 25 female; mean age = 22.37 ± 5.64 years, range = 18–43 years; 36 right-handed, 2 left-handed.
- Boost-first: n = 40; 19 male, 21 female; mean age = 21.82 ± 4.84 years, range = 18–39 years; 36 right-handed, 4 left-handed.
- No boost control: n = 39; 7 male, 32 female; mean age = 22.62 ± 6.70 years, range = 18–49 years; 38 right-handed, 1 left-handed.

The session lasted approximately one hour. No participants withdrew from the study, and no adverse effects were reported.

Setup and materials

Experiment 2 was performed using the Meta Quest 3. Hand movements were tracked using the headset's built-in markerless hand-tracking system. The experiment was implemented as a WebXR application programmed in JavaScript/HTML using the A-Frame framework and run in the built-in Quest Browser.

Targets were presented at 11 locations spanning −40° to +40° relative to the participant's body midline (−40°, −32°, −24°, −16°, −8°, 0°, 8°, 16°, 24°, 32°, 40°). This narrower target range, relative to Experiment 1, was chosen to optimise hand-tracking performance.

Procedure

The session began in the same way as Experiment 1, including headset fitting, re-centring, and reach calibration. Two additional calibration steps were then performed. Target elevation was adjusted to sit just below eye level while participants looked comfortably straight ahead. The left- and right-hand home positions were then set while participants rested both hands comfortably on their lap.

Each trial began when both hands were detected within their respective home positions. After a fixed delay of 500 ms, a single target appeared at one of 11 possible locations. Targets were selected randomly, with the added constraint that immediate repetitions of the same target location were not permitted. Target locations were not spatially jittered. No fixation cross was displayed between trials.

Participants were instructed to intercept the target using either hand. A hit was registered when the virtual hand mesh collided with the target sphere, at which point the target disappeared and game points were awarded. A sound was also played to the participant. Game points could fall within a lower range (normal hit: 1 – 5) or a higher range (critical hit: 5 – 10). Normal hits were accompanied by a bubble-popping sound; critical hits were accompanied by a reward tone. Points were integers, and values were sampled uniformly from within each range.

There were two point-schedules: Balanced and Boost. In the Balanced schedule, critical-hit probability was identical for both hands (30% for each hand). In the Boost schedule, critical hits favoured the non-dominant hand (55% for the non-dominant

hand; 5% for the dominant hand). Each participant completed two blocks of 352 trials, labelled Time 1 and Time 2, separated by a 5-minute rest period.

Participants were assigned to one of three Sequence groups: Boost-second (Balanced at Time 1; Boost at Time 2), Boost-first (Boost at Time 1; Balanced at Time 2), or No boost control (Balanced at both Time 1 and Time 2; Fig. 3).

After the experimental task, participants completed three questionnaires: a brief awareness questionnaire, the System Usability Scale (SUS) and the Intrinsic Motivation Inventory Task Evaluation Questionnaire, IMI-TEQ (Ryan 1982; Ryan et al. 1983; Brooke 1996). The first seven participants in the Boost-second group did not complete the SUS and IMI-TEQ questionnaires because they had not yet been implemented into the study protocol.

Dependent measures and analyses

Hand choice and PSEs were estimated as described in General methods.

Hand choice. To test whether hand choice differed across time as a function of Sequence, PSE estimates were computed separately for each participant at Time 1 and Time 2 and entered into a mixed ANOVA with Sequence (Boost-second, Boost-first, No boost control) as a between-participant factor and Time (Time 1, Time 2) as a within-participant factor.

To test whether the effect of the reward manipulation depended on block order, PSEs from the Boost-second and Boost-first groups were analysed using a mixed ANOVA with Order (Boost-second, Boost-first) as a between-participant factor and Point Schedule (Balanced, Boost) as a within-participant factor.

Awareness of manipulation. After the experimental task, participants completed a brief awareness questionnaire. Participants were asked:

(1) Did you notice any changes between the two game sessions?
(2) Did you use one hand more than the other?
(3) Do you think the score mechanic motivated you or not?

Usability and task evaluation. SUS responses were converted to 0-100 scores, with higher scores indicating greater perceived usability (Brooke 1996). IMI-TEQ items were reverse-scored where appropriate and averaged within each subscale in accordance with established guidance (Ryan et al. 1983).

Results and discussion

Point schedule alters hand choice

Biasing game points in favour of the non-dominant hand systematically alters hand choice. Figure 4 shows this effect as sequence-dependent changes in the relationship between target position and percentage dominant-hand use, and in the corresponding participant-level PSE estimates. The hand-choice functions shift to reflect greater non-

dominant-hand use when the Boost schedule is presented, whereas the No boost control group shows little change across repeated Balanced blocks. A mixed ANOVA on the PSE estimates confirms this pattern, revealing a significant Time × Sequence interaction ($F(2, 114) = 13.51$, $p < 0.0001$; $\eta^2_p = 0.192$, 95% CI [0.073, 0.311]).

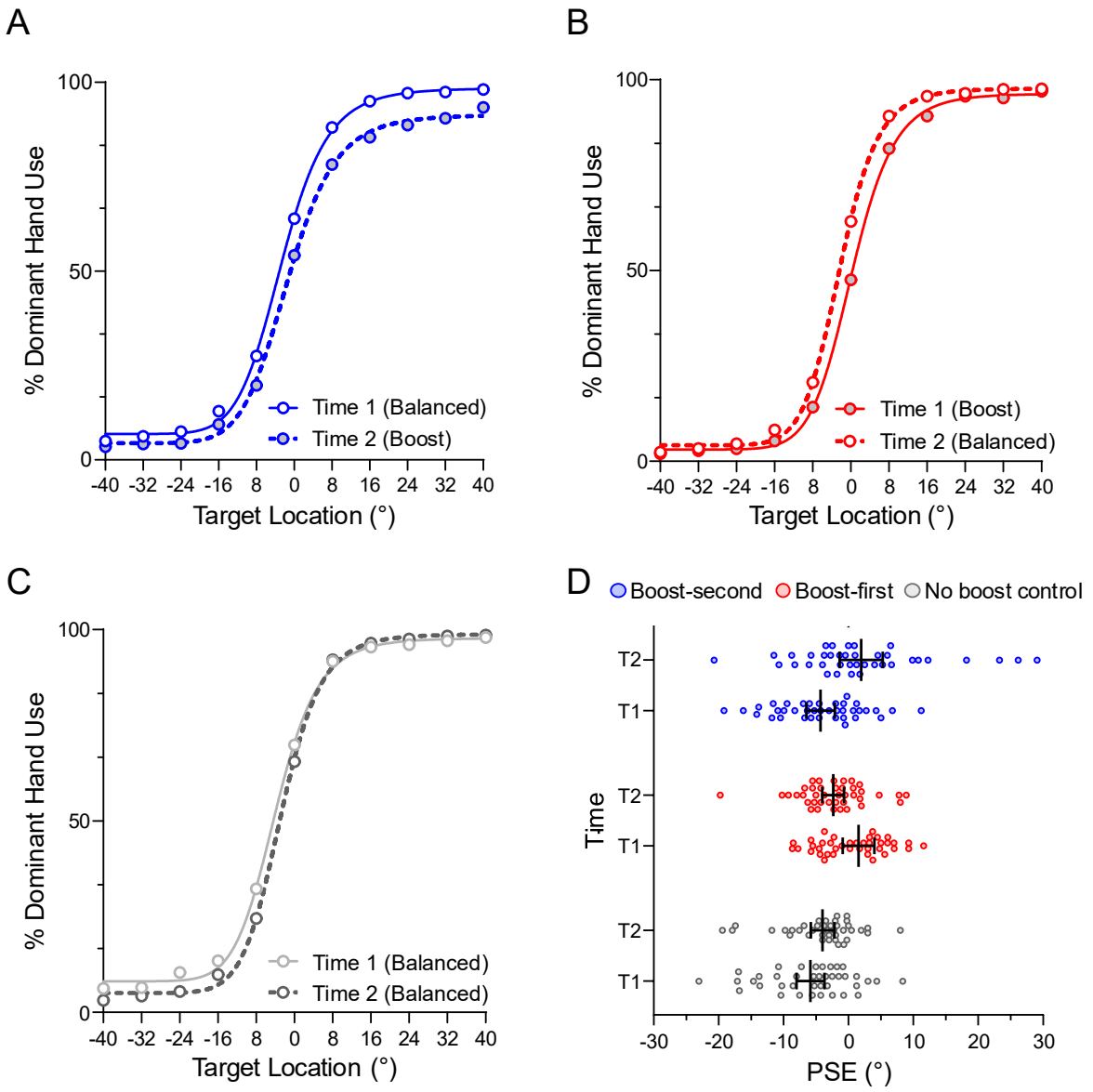


Figure 4. Effect of point manipulation on PSEs. A: Group-level psychometric fits for the Boost-second (blue) group. Solid and dashed lines show Time 1 and Time 2, respectively. **B-C**: Equivalent group-level psychometric fits for the Boost-first (red) and No boost control (grey) groups, respectively. **D:** PSE estimates across time points for each sequence group. Coloured points show individual participant PSEs. Error bars show group means ± 95% CIs. The dashed vertical line indicates 0°. Negative PSE values indicate greater dominant-hand use, whereas positive values indicate greater non-dominant hand use.

Follow-up tests verify that the interaction reflects selective changes in the groups exposed to the Boost schedule. In the Boost-second group, participants use the non-dominant hand more often at Time 2, when the Boost schedule is introduced, producing a reliable increase in the PSE estimates relative to the Balanced block at Time 1 (ΔPSE = +6.25°, 95% CI [2.72, 9.77]; t(114) = 4.45, p < 0.0001). In the Boost-first group, the same pattern is observed in the opposite temporal direction: participants use the non-dominant hand more often during the Boost block at Time 1 than during the Balanced block at Time 2 (ΔPSE = +3.91°, 95% CI [0.59, 7.23]; t(114) = 2.86, p = 0.015). In contrast, the No boost control group shows no reliable change in PSE from Time 1 to Time 2 (ΔPSE = +1.86°, 95% CI [−1.62, 5.34]; t(114) = 1.34, p = 0.484; BF_{10} = 0.769).

Together, these results show that the Boost schedule shifts hand choice toward the non-dominant hand. This shift is observed when the Boost schedule is introduced after an initial Balanced block and when it is presented before a Balanced block. By contrast, hand choice remains relatively stable across repeated Balanced blocks in the No boost control group. The observed PSE shifts are therefore linked to the change in game-point schedule, rather than to time, practice, or task exposure.

Dominant hand use declines progressively within Boost blocks

The effect of the Boost schedule should emerge over time, through experience with the point schedule. We therefore inspected whether dominant-hand use changed progressively within each block. To do this, trials are grouped by target occurrence, where each occurrence reflects another presentation of the full target array. This allows us to track hand choice over time while averaging over the spatial effect of target position. Dominant-hand use is then modelled as a function of target occurrence separately for each participant and block. Negative slopes indicate a progressive decline in dominant-hand use.

Figure 5 shows that dominant hand use declines across target occurrences during Boost blocks. This pattern is clearest in the Boost-second group, where the Boost schedule is introduced at Time 2 and dominant-hand use declines reliably within the block (t(37) = 3.15, p = 0.003, p_{adj} = 0.019; d = −0.51, 95% CI [−0.89, −0.19]) (Fig. 5A). The Boost-first group shows a similar negative slope during the Boost block at Time 1, although this effect does not survive correction for multiple comparisons (t(39) = 2.25, p = 0.030, p_{adj} = 0.169; d = −0.36, 95% CI [−0.71, −0.05]) (Fig. 5B). By contrast, Balanced blocks show no evidence of systematic change in hand use over time (all p > 0.08; all p_{adj} > 0.40; all BF_{10} < 0.731). Together, these results show that the effects of the reward manipulation unfold over the course of the Boost block.

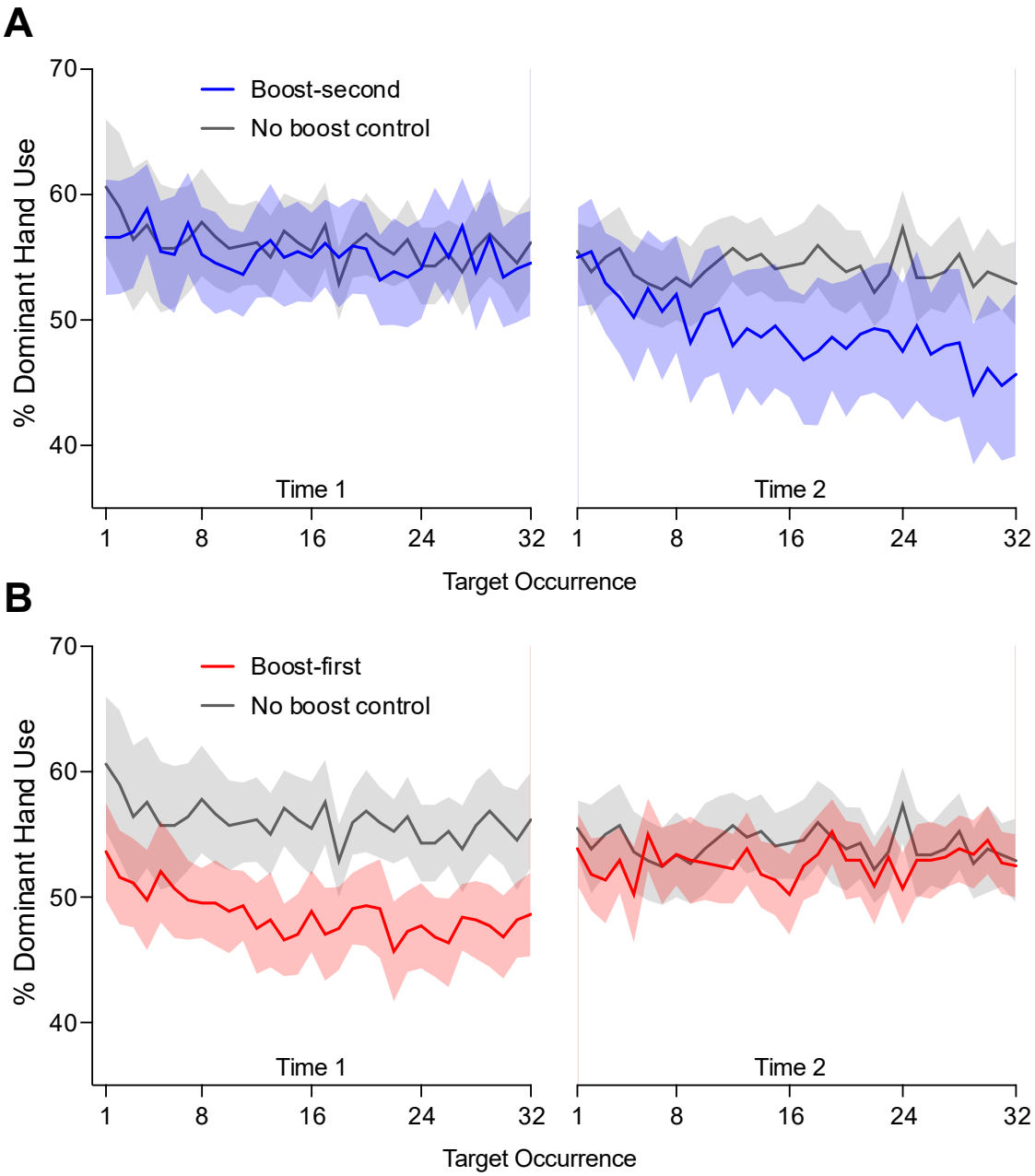


Figure 5. Dominant-hand use across target occurrences. Group-level dominant hand use as a function of target occurrence, shown separately for Time 1 and Time 2. Target occurrence refers to the number of times the full target array had been presented within a block, from the first to the 32nd occurrence. Lines show group means. Shaded areas show 95% CIs. **Panel A** shows the above for the Boost-second (blue) and the No boost control (grey) groups, while **Panel B** shows the above for the Boost-first (red) and No boost control (grey) groups.

Block order does not reliably moderate the point-schedule effect

The primary analyses show that hand choice changes selectively in groups exposed to the Boost schedule. We next asked whether the size of this effect depends on block order. This analysis focused on the two groups that completed both point schedules, because only these groups provide a within-participant comparison between Balanced and Boost blocks.

The reward manipulation systematically shifts hand choice toward the non-dominant hand, with no credible evidence that this effect depends on whether the Boost schedule is experienced first or second. An ANOVA reveals no significant Order x Point Schedule interaction ($F(1, 76) = 1.15$, $p = 0.286$; $\eta^2_p = 0.015$, 95% CI [0, 0.108]; $BF_{Incl} = 0.303$), and no main effect of Order ($F(1, 76) = 0.33$, $p = 0.564$; $\eta^2_p = 0.004$, 95% CI [0, 0.077]; $BF_{Incl} = 0.224$). In contrast, PSEs shift to indicate greater non-dominant hand use in Boost blocks compared with Balanced blocks, confirmed as a significant main effect of Point Schedule ($F(1, 76) = 21.81$, $p < 0.0001$; $\eta^2_p = 0.223$, 95% CI [0.079, 0.375]; Fig. 6A). Together, these results indicate that the Boost schedule shifts hand choice toward the non-dominant hand, with no credible evidence that this effect depends on block order.

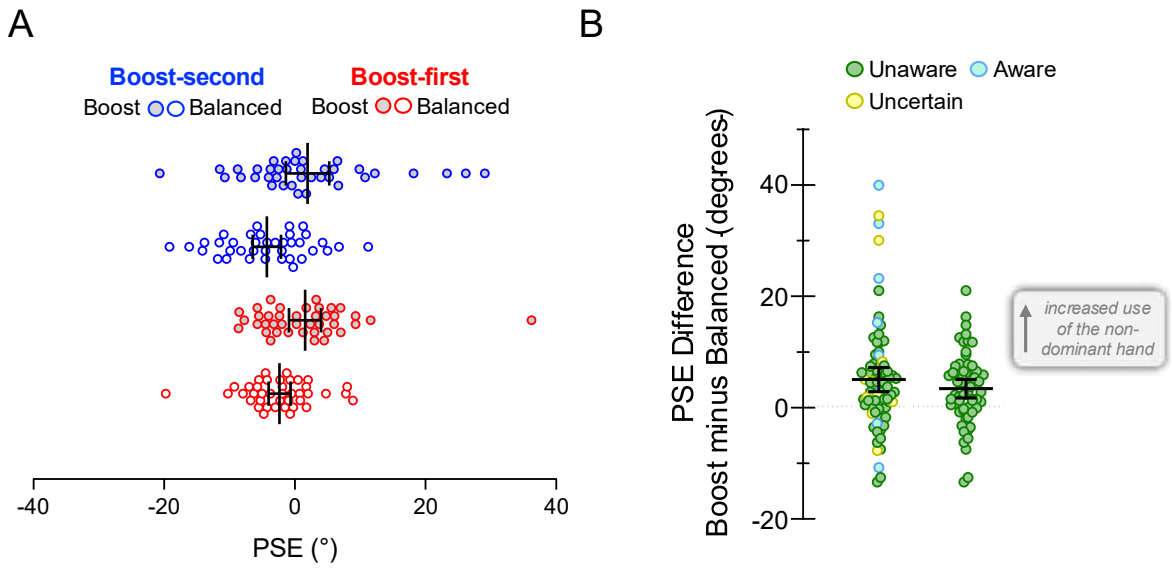


Figure 6. Boost-Balanced PSE differences and manipulation awareness. A: Individual PSE estimates for Boost and Balanced blocks, shown separately for the Boost-second (blue) and Boost-first (red) groups. Coloured points show individual participant values. Error bars show group means ± 95% CIs. The dashed vertical line indicates 0°. **B:** Difference in PSE between Boost and Balanced blocks, collapsed across sequence order. Positive values indicate a shift toward greater non-dominant-hand use in Boost blocks. Points show individual participants, coloured according to awareness of the point manipulation: unaware (green), answer uncertain (yellow), or aware (cyan). Right distribution shows the same data excluding participants classified as aware or uncertain. Error bars show group means ± 95% CIs.

Point-schedule alters hand choice without explicit awareness

Explicit awareness of the point-schedule manipulation was uncommon. Most participants either reported no difference between blocks or described perceived differences that did not correspond to the true manipulation (Table 1). These participants were classified as unaware. Only eight participants exposed to the Boost schedule correctly identified the true reward manipulation and were classified as aware (8/78; 10.3%). A further 13 participants gave inconclusive responses and were classified as uncertain.

Group	N	Excluded (uncertain)	Interpretable n	No difference noticed	Noticed difference (incorrect)	Correctly identified manipulation
Boost-second	38	7	31	18 (58%)	7 (23%)	6 (19%)
Boost-first	40	3	37	20 (54%)	15 (41%)	2 (5%)
No boost control	39	3	36	24 (67%)	12 (33%)	0 (0%)

Table 1. *Awareness of the point-schedule manipulation by group. Percentages are of interpretable n (i.e. excluding ambiguous responses). Participants were classified as aware if they explicitly reported that one hand received more points than the other. Participants were classified as unaware if they did not identify the reward manipulation. Participants were classified as uncertain if they reported noticing a difference between blocks but did not provide enough information to determine whether they had identified the actual manipulation. Since the no boost control group had no actual manipulation, "noticed difference (incorrect)" responses in that group are false positives.*

Figure 6B shows the point-schedule effect for the full dataset, with participants labelled according to awareness classification. Positive values indicate greater non-dominant-hand use in Boost blocks relative to Balanced blocks, and therefore indicate the expected effect of the point-schedule manipulation.

Critically, the point-schedule effect persists in participants classified as unaware. After excluding participants classified as aware or uncertain, PSE estimates remain reliably shifted toward greater non-dominant-hand use in Boost blocks compared with Balanced blocks ($t(59) = 4.08$, $p = 0.0001$; $dz = 0.53$, 95% CI [0.26, 0.80]; Fig. 6B, right). Thus, participants use their non-dominant hand more often in response to the game-point reward manipulation imposed by the Boost schedule, even when they are not explicitly aware of this manipulation.

Participants report high usability and a positive task experience

Participants rated the VR system as highly usable and reported a positive task experience (Table 2). Interest and enjoyment were moderate to high, perceived competence was moderate, perceived choice was high, and pressure/tension was low. Scores were similar across Sequence groups, indicating that subjective experience of the task did not differ systematically by group assignment. Together, these data

indicate that the VR task was usable, well tolerated, and positively evaluated by participants.

	Boost-second			Boost-first			No boost control		
Measure	**M**	**SD**	**Range**	**M**	**SD**	**Range**	**M**	**SD**	**Range**
SUS	79.83	11.93	50.00–97.50	83.25	11.65	55.00–100.00	81.88	10.87	50.00–97.50
IMI Interest/Enjoyment	5.05	1.20	2.86–7.00	4.90	1.14	2.71–7.00	4.69	1.41	1.43–7.00
IMI Competence	4.79	1.06	2.20–6.80	4.76	0.99	2.60–6.60	5.01	0.82	3.00–6.80
IMI Choice	6.29	0.64	4.60–7.00	6.17	0.71	4.60–7.00	6.22	0.59	5.00–7.00
IMI Pressure/Tension	1.93	0.95	1.00–4.00	2.08	0.84	1.00–4.20	1.76	0.56	1.00–2.80

Table 2. *Descriptive statistics for SUS and IMI–TEQ subscales by group. SUS scores range 0–100 (higher = greater perceived usability). IMI–TEQ subscales range 1–7; higher scores indicate greater levels of the named construct. M = mean; SD = standard deviation; Range = min–max.*

General discussion

Across two experiments, we show that established principles of hand choice remain evident in immersive VR. In Experiment 1, both hand choice and decision times reflect predicted action costs. The point in target space where the use of either hand is equally probable falls close to the body midline, where inter-limb biomechanical and energetic costs are comparable, and participants take longer to initiate movements to targets near this point when hand choice is free. In Experiment 2, changing the game's point structure systematically influences hand choice. When points favour one hand, participants adjust their hand choice to increase rewards. These effects occur even when participants are unaware of the reward manipulation. Together, our results show that hand choice in VR is influenced by both target position and reward structure, consistent with a utility-based account in which competing actions are evaluated according to their predicted costs and expected benefits.

Movement control

Our findings extend previous work on movement control in virtual environments by showing that established principles of action selection also operate in immersive VR. Previous investigations have largely focused on how movements are performed, with less attention given to how actions are selected. In VR, some visual depth cues are altered, physical contact and haptic feedback are reduced or absent, and the appearance and movement of virtual limbs need not correspond precisely to the physical body (Harris et al. 2019). These differences alter the information available for movement planning and selection, and, in principle, could influence estimates of the costs and expected outcomes of potential actions during planning and selection.

Studies comparing physical and virtual environments reveal both differences and continuities in movement control. Some report slower and more exaggerated movements in VR (Magdalon et al. 2011; Furmanek et al. 2019). Harris et al. (2025) for example, find slower reach velocities during virtual object lifting, consistent with a more controlled approach. Conversely, other work reveals highly similar movements between environments. Yamamoto et al. (2025) find that the relative time to peak velocity is shorter for upward than downward reaching movements in both physical and virtual environments. This asymmetry is understood to reflect an effort-minimising strategy that exploits gravity, consistent with movements being planned and controlled in relation to their energetic costs. Hierarchical Bayesian modelling of these same data reveals broadly similar expectations about gravity across environments, but a steeper decline in their precision over successive trials in VR (Yamamoto et al. 2026).

Together, these findings suggest that established principles of movement control remain evident in VR, even when aspects of movement performance and internal estimates supporting the control of movements differ. Our results extend this work to action selection, showing that hand choice in immersive VR remains sensitive to factors known to influence action selection in physical environments, including predicted movement costs and expected reward.

Predicted movement costs

Experiment 1 shows that established effects of target location on hand choice and movement-initiation times extend to immersive VR. Hand choice varies systematically with target position. Targets near the body midline elicit more balanced hand use, whereas more lateral targets favour the ipsilateral hand. The PSE quantifies this transition point, identified near the midline but, at the group level, shifted into left space, indicating more frequent use of the dominant right hand. Movement-initiation times show a complementary pattern: participants take longer to initiate movements to targets near the PSE, and, critically, these effects are specific to the Choice condition, where participants are free to choose which hand to use. Together, the spatial gradient in hand choice and the choice-specific increase in movement-initiation times reproduce findings from conventional reaching studies (Oliveira et al. 2010; Stoloff et al. 2011; Fitzpatrick et al. 2019; Valyear et al. 2019; Fitzpatrick et al. 2022).

Our results are consistent with a utility-based account of hand selection in which competing actions are chosen according to their predicted costs and benefits. Target position changes the relative biomechanical and energetic costs of reaching with each hand (Gordon et al. 1994; Schweighofer et al. 2015). A preference for the ipsilateral hand at lateral target positions is consistent with selection favouring the less costly action. The leftward offset of the PSE suggests that the dominant right hand also carries a persistent expected advantage. The pattern is consistent with a utility-based interpretation: choices reflect interlimb differences in energetic and biomechanical costs associated with reaching to different areas of space, combined with a modest bias favouring the dominant hand.

Movement-initiation times provide evidence of a competitive process underpinning hand choice. Participants take longer to move when reaching to targets near the PSE, where those interlimb differences in energetic and biomechanical costs are minimal. Because these effects are specific to free-choice trials and are not observed when hand use is instructed, they cannot be explained by differences in movement complexity or attentional demands. Instead, they reflect differences in the time taken to decide which hand to use. Thus, both hand choice and decision times in immersive VR reflect predicted action costs.

Previous investigations of hand choice in VR environments provide complementary evidence. Using a protocol where participants reach to targets on a computer screen while their hands are tracked and displayed as virtual hands, McDermott and Himmelbach (2019) found that lateral targets are reached mainly with the ipsilateral hand. They estimate the transition between left- and right-hand use with a measure called the reaching-frequency midline, conceptually similar to the PSE used in the current study. Although they do not directly test its displacement from centre, the reaching-frequency midline was observed to the left of centre in their group of right-handed participants, consistent with our results.

Their investigation tests how target height and weight added to the non-dominant hand influence hand choice. Both manipulations were found to increase dominant-hand use, and both effects can be understood within the utility-based framework. Raising targets increases reaching distance, potentially increasing the effort and accuracy demands of the movement. Under these conditions, the dominant hand may be expected to perform more effectively, increasing its relative expected benefit. Added weight instead increases the effort required to use the non-dominant hand, biasing choice in favour of the dominant hand as the less costly alternative. In both cases, hand choice shifts toward the action with greater expected utility.

Sakabe et al. (2021) provide further evidence from immersive, headset-based VR. In their task, participants choose which hand to use to reach to targets arranged around the body midline, and hand choice is quantified using a PSE-like border-angle measure. At baseline, the border angle is identified to the left of centre in their right-handed participants, consistent with our results; as in McDermott and Himmelbach (2019), however, this displacement from centre is not directly tested. Adding weight to the dominant forearm shifts choices away from that hand. This effect is partly reversed when the weighted virtual hand is displayed as moving farther than the real hand for the same physical movements. Participants then use the weighted hand more often; the visual manipulation partly counteracts the effect of the added weight.

Sakabe et al. (2021) interpret this visual amplification effect as positive reinforcement and suggest that altered visual feedback may affect participants' sense of agency over the weighted hand. Their data can also be interpreted within a utility-based framework. Visual amplification may reduce predicted movement costs, because the virtual hand can reach a target with less physical effort. The continued increase in weighted-hand use after amplification is withdrawn suggests that recent experience matters beyond the immediate change in the movement required to reach a target. Their study does not isolate these possible mechanisms, but shows that changing the visual outcome of a reach can alter subsequent hand choice in immersive VR.

Expected reward

Experiment 2 shows that game points can moderate hand choice in immersive VR. When high-value game points favour the non-dominant hand, participants use that hand more often, expressed as a corresponding shift in the PSE in the predicted direction. These effects are tied to the Boost schedule and do not depend on whether the Boost manipulation is experienced first or second. By contrast, hand choice remains relatively stable across repeated blocks of the Balanced condition, when expected reward is balanced between hands. These results indicate that changes in hand use reflect the game-point manipulation rather than time, practice, or repeated task exposure. Within-block analyses show that dominant-hand use declines progressively during the Boost manipulation, consistent with participants adjusting their choices through experience with the point schedule.

The game-point effects do not appear to require explicit awareness. After excluding participants who correctly identify the reward manipulation, and those whose responses are ambiguous, the effects persist. Participants use their non-dominant hand more often in the Boost condition, even when they do not explicitly report noticing that this hand is associated with a higher probability of obtaining high-value points. This suggests that, at least in these participants, the Boost manipulation biases hand choice through some kind of implicit cumulative learning, rather than through an explicit strategy to select the hand associated with higher-value rewards. Comparable effects have been reported in other experiments involving reaching and grasping, where recent experience shapes movement-initiation times and in-flight kinematics more strongly than explicit knowledge of upcoming task conditions (Song and Nakayama 2007; Whitwell et al. 2008; Whitwell and Goodale 2009).

The results of Experiment 2 closely align with Stoloff et al. (2011). Our paradigm follows the same general design: targets are distributed across the body midline, participants choose which hand to use, and hand choice is quantified using psychometric functions to estimate PSEs. Stoloff et al. test whether hand choice changes when success and reward are made asymmetric between hands. They manipulate limb-dependent reinforcement by making successful reaches (“hits”) more likely with the non-dominant hand, less likely with the dominant hand, or both. Across these manipulations, participants increase their use of the non-dominant hand, especially near the PSE. They also show that these changes occur with limited explicit awareness and are captured by a simple reinforcement-learning model, in which recent successes and failures update the value assigned to each hand at each target location. Their model formalises the idea developed above: hand choice can be shaped by recent reward history without explicit knowledge of the relationship between hand use and reward.

The present manipulation differs in an important respect. In Stoloff et al. (2011), reinforcement is coupled to movement performance: their manipulation changes how likely reaches with each hand are to qualify as successful hits. The non-dominant hand is therefore not only associated with greater expected reward, but is also made more successful at the task. In our study, the hand-specific reward asymmetry is not coupled to motor performance in this way. The hit criterion is unchanged; instead, the Boost schedule changes the distribution of points awarded after successful reaches, making high-value outcomes more likely following non-dominant-hand use. This distinction suggests that game points can bias hand choice even when movement performance itself is unchanged.

Our findings show that manipulating game points can shift hand choice in immersive VR in a predictable direction. When the point schedule favours the non-dominant hand, participants shift their choices toward that hand. This pattern is consistent with the utility-based framework outlined in the Introduction, in which increasing the expected reward associated with one hand increases the relative utility of actions performed with that hand. Together with Experiment 1, these results suggest that hand

choice in VR remains sensitive to both predicted movement costs and expected reward. The positive usability and task-experience ratings further indicate that this reward manipulation was delivered in a VR task that participants tolerated and evaluated positively.

Implications for rehabilitation

The present findings provide a principled starting point for developing VR-based rehabilitation tools that target hand choice. Within a utility-based framework, unilateral motor impairment alters the relative costs and expected benefits of actions performed with either arm. Movements of the affected arm may require greater effort, take longer to complete, induce pain and fatigue, and be less likely to succeed. This may reduce their relative utility and favour selection of the less-affected arm. The strength of this bias should depend on impairment severity and task demands. Thus, reduced affected-arm use may reflect, at least in part, the same action-selection principles observed in healthy individuals, operating under substantially altered motor constraints.

Rehabilitation, however, introduces an additional consideration. Patients may choose to use their affected arm despite its immediate disadvantages because they anticipate therapeutic benefits from repeated practice. These anticipated benefits may offset some of the immediate costs, depending on how strongly patients expect affected-arm practice to contribute to recovery.

Existing VR-based rehabilitation applications have begun to explore ways of encouraging voluntary affected-arm use. In *Project Star Catcher* (Elor et al. 2018a; Elor et al. 2018b), stroke survivors can choose either arm to intercept moving targets—'stars'—presented at different locations and speeds. The game encourages affected-arm use by awarding higher scores for catches made with that arm, alongside colour cues and differentiated auditory and vibratory feedback intended to make these actions more engaging.

Altukhaim et al. (2025) adapted the visual-amplification protocol of Sakabe et al. (2021), discussed above, for stroke survivors. In their free-choice reaching task, visual amplification makes the affected virtual arm appear to move farther than the physical arm for the same movement. As discussed above, this manipulation may reduce predicted movement costs by allowing targets to be intercepted with less physical effort, while potentially increasing the expected likelihood of success.

These studies demonstrate the feasibility of delivering immersive VR interventions in which patients can choose either arm, while reward and sensory feedback are manipulated to encourage affected-arm use. Whether such approaches produce meaningful clinical benefits remains uncertain; adequately controlled efficacy trials are needed.

The current findings establish that factors known to govern hand choice in physical environments remain influential in immersive VR, and that game-based rewards can

systematically alter which hand is selected. These results provide a behavioural foundation for developing rehabilitation tools that encourage voluntary affected-arm use by modifying the relative costs and expected benefits of competing actions. Whether comparable manipulations can reliably influence hand choice in stroke survivors, and whether such interventions can produce clinically meaningful improvements in upper-limb function, remain important questions for future research.

Declarations

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