Designing Social Feedforward for VR Resistance Training: Competition Improves Performance, Friends Improve Enjoyment

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Abstract

Resistance training improves strength and health, but many people under-participate. Resistance training also follows distinct patterns and determinants from aerobic exercise. Exergames are proposed to motivate those with low drive, but guidance for gamifying resistance training is scarce. We built a VR cable-machine exergame that used feedforward, a visual trace/model of prior performance that guides ongoing movement to create replay avatars (ghosts). In a 2 (Mode: cooperation vs. competition) × 3 (Target: self, friend, stranger) within-subjects study, 30 participants experienced all six conditions while we logged movement quality and self-reports. Results revealed a dissociation: competition enhanced movement quality (score and repetitions), whereas target identity influenced affect, with friend feedforward elevating enjoyment relative to a stranger. Individual differences moderated these effects: Big-Five traits and friendship quality selectively shaped affect and competence beliefs. These findings show how mode, relationship, and personality jointly influence outcomes, motivating adaptive VR exergames that personalize social feedforward.

Keywords

Virtual reality, Exergames, Strength training, Social games, Games for health

1. Introduction

Resistance training improves muscular strength and power, bone density, functional capacity, and cardiometabolic health, and regular participation is associated with reduced all-cause and cardiovascular mortality [1, 2]. Guidelines therefore recommend muscle-strengthening activities at least two days per week alongside aerobic exercise [3, 4]. Despite these benefits, adherence to strength training remains low, suggesting a need for more engaging and sustainable training experiences.

Immersive Virtual Reality (VR) exergames can increase enjoyment and motivation during exercise and may support adherence [5]. However, most studied VR exergames emphasize light-to-moderate, largely aerobic exertion, often prioritizing affect over high-load strength work [5]. Recent evidence indicates that resistance-oriented VR is feasible and can elicit vigorous intensity with high enjoyment and muscle activity comparable to traditional lifts [6], with randomized trials reporting comparable or superior training outcomes relative to conventional programs [7, 8]. Yet this emerging work largely evaluates VR *as a training modality* (VR vs. non-VR) and provides limited guidance on how *interaction design choices within VR* shape movement quality and motivation—critical concerns in resistance exercise where technique and safety are central.

A promising interaction mechanism is *interactive feedforward*: interface cues that preview action outcomes to guide users before execution [9, 10]. In exergames, feedforward "ghost" traces provide an immediate performance target, improving high-intensity cycling performance while maintaining intrinsic motivation [11, 12]. More recently, *social* interactive feedforward—using a *friend* model rather than self or a stranger—further increased performance and intrinsic motivation [13]. However, it is

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unknown whether these benefits generalize from primarily aerobic tasks to high-load resistance exergames, or how feedforward interacts with social play configurations such as cooperation and competition.

Social play is a key determinant of exergame outcomes: competition can increase effort and intensity, whereas cooperation can support enjoyment, efficacy, and persistence, with effects depending on context and comparison targets [14, 15, 16]. Beyond mechanics, individual differences may shape who benefits from which social augmentations. In sport and exercise, Big Five personality traits and relationship quality relate to activity patterns and performance (e.g., conscientiousness and extraversion often correlate with success; neuroticism tends to relate to lower efficacy) [17, 18]. Yet personality and friendship have rarely been integrated into the design or evaluation of VR exergames, particularly for resistance training.

In this paper, we present a VR cable-machine exergame that factorially combines social mode (cooperation vs. competition) with social feedforward targets (self vs. friend vs. stranger). Using a standardized isolation lift (standing triceps pulldown), we investigate how these social augmentation mechanisms influence movement performance and intrinsic motivation, and how effects depend on personality and friendship quality. We address the following research questions:

RQ1. How do social interaction modes (cooperation vs. competition) and target types (self, stranger, friend) influence players' movement performance and intrinsic motivation in a VR cable-machine exergame?

RQ2. How do individual personality traits (Big Five) influence differences in motivation (interest, effort, pressure, competence) and experiential outcomes (flow, movement synchrony) during social VR exergame play?

RQ3. In what ways do qualities of friendship (e.g., conflict, companionship, intimacy) moderate the effects of personality on motivational and competence outcomes in friend-based gameplay?

RQ4. How do cooperative and competitive settings amplify or mitigate the interaction between personality and friendship quality?

Our contributions are:

1. **Social feedforward for resistance VR.** A controlled within-application study in a VR cable-machine exergame that systematically varies social mode (competition vs. cooperation) and feedforward target (self, friend, stranger), extending prior feedforward work to high-load resistance training.
2. **Mode–target dissociation.** Evidence that how people play (competition vs. cooperation) and who they play against (self/friend/stranger) can have separable effects on movement performance versus affective experience.
3. **Individual-differences-aware social augmentation.** Mixed-effects analyses showing selective moderation by Big Five traits and friendship dimensions, motivating trait- and relationship-aware design.
4. **Design implications.** Practical guidance for adaptive resistance VR, leveraging competitive/-cooperative blocks and personalized feedforward targets to support technique, enjoyment, and pressure management.

2. Related Work

Most VR exergame research targets body-weight or aerobic activity, while resistance-oriented systems remain comparatively scarce [19, 20, 21, 22]. Cable-based VR exergames have received the most systematic attention, but much of the evidence concentrates on a single commercial product that maps push–pull actions to in-game attacks and missions [23]. Existing evaluations suggest promising acute

Figure 1: The exergame in two modes with a ghost target. Left: *cooperation*, players face a shared boss enemy and work together with a front-facing ghost. Right: *competition*, players fight through identical enemy waves while a progress bar and per-rep score display relative performance against a rival ghost.

and longitudinal outcomes, yet the evidence base is narrow in terms of interaction design: studies typically compare one VR application against conventional training rather than testing different mechanisms within the same resistance VR system [24, 6, 7, 8]. As a result, it remains unclear how specific in-app design choices shape movement quality and motivation in resistance VR.

Feedforward provides information before action so users can anticipate outcomes, and in exergames it often appears as trajectory overlays or "ghost" models that preview intended patterns [9]. Prior work shows that interactive feedforward can improve performance while sustaining intrinsic motivation, including self-competition designs over time [11, 12], and that social feedforward (friend vs. self/stranger targets) can further enhance performance and intrinsic motivation [13]. Separately, social play configurations matter in exergames: competition can raise effort and performance, whereas cooperation can support enjoyment and persistence depending on context [15, 16]. However, these strands are rarely examined together in resistance-based VR. Our study addresses this gap by varying social mode and feedforward target within a VR cable-machine exergame to test their joint impact on movement performance and experience.

3. Exergame Design

3.1. Hardware Setup

This study employed a combined hardware setup consisting of a VR headset, a custom 3D printed connector, and a commercial cable machine. The setup enabled standardized resistance exercise in VR while logging handle trajectories for later replay as ghost targets. Figure 3 illustrates the avatar representation, the connector, and the integrated in-use setup.

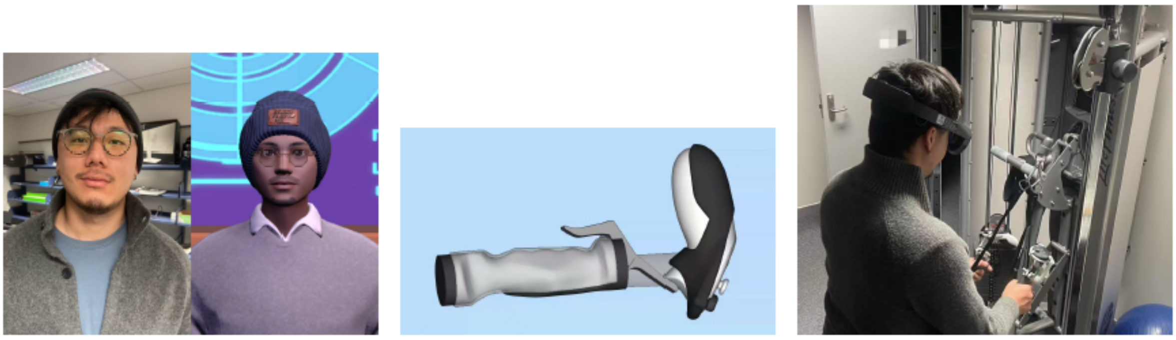
3.2. Mechanics

We designed a science-fiction themed VR setting in which players' resistance actions were mapped to weapon energy against alien invaders. Each repetition produced a laser attack whose damage scaled with movement quality, so technique directly determined in-game outcomes. We implemented three gameplay modes: solo, competitive, and cooperative. Figure 2 illustrates the spatial layout, ghost embodiment, and interface differences between cooperative and competitive modes.

Single-player mode. In the solo condition, participants trained individually against continuously emerging enemies. It generated historical movement data used to construct feedforward targets in subsequent conditions.

Competitive mode. In the competitive condition, users played simultaneously with a ghost generated from prior performance data and confronted identical waves of enemies. While positioned side by

Figure 2: Mechanics overview of the VR cable-machine exergame. Left: **Cooperation.** Two players share a boss enemy (1) in a common activity space (2). A replay-based ghost stands in front-facing alignment with the player (3), reproducing prior movement trajectories and firing patterns. Damage contributes to a shared boss HP pool. Right: **Competition.** Players encounter identical enemy waves (4) in parallel lanes. Each player's damage and repetition-level score are computed independently and visualized via HUD feedback (5), including enemy HP and relative performance indicators. Floor markers (6) provide spatial reference for positioning and pacing.



(a) Left: participant photo. Right: automatically generated `Ready Player Me` avatar (shown with written consent).

(b) Custom 3D-printed connector rigidly attaching the VR controller to the cable handle.

(c) Participant wearing a VR headset while performing the exercise with the integrated setup.

Figure 3: Hardware setup of the VR cable-machine exergame.

side, their damage contributions were scored independently, with a real-time progress bar visualizing relative performance.

Cooperative mode. In the cooperative condition, users worked together with a ghost generated from prior performance data (self, friend, or matched stranger) to defeat a high-durability boss enemy.

In both modes, the ghost is rendered as a full-body avatar positioned at a fixed frontal offset relative to the player's viewpoint, facing the same enemy direction. The ghost replays previously recorded movement trajectories and corresponding firing patterns in real time, without reacting to the current player. This replay-based feedforward allows participants to anticipate pacing and execution patterns before and during each repetition.

3.2.1. Movement Quality Scoring System

To estimate repetition-level movement quality, we computed a weighted score that combines (i) similarity between the current repetition and the immediately preceding one (normalized to [0,1]), and (ii) movement smoothness measured using normalized Dimensionless Squared Jerk (DSJ) [25, 26, 27]. Higher similarity and smoother motion yield higher scores:

$$\text{MeanScore}_i = 0.7 \cdot \text{Sim}_i + 0.3 \cdot (1 - \text{DSJ}_i) \tag{1}$$

3.2.2. Feedforward

We used the Ready Player Me avatar creation platform [28] to generate personalized 3D avatars from a single photograph for representing partners or opponents, as illustrated in Figure 3a. After each game concludes, prior performance logs are used to drive feedforward visualizations, where the ghost replays scoring frequencies and firing patterns derived from recorded movements.

4. User Study Methodology

We conducted a within-subjects 2 × 3 study with factors Mode (Competition vs. Cooperation) and Feedforward Target (Self vs. Friend vs. Stranger), yielding six conditions across two lab sessions.

Procedure. Participants were recruited in self-selected dyads and attended with a pre-existing friend. After consent, they completed baseline questionnaires (BFI-10, IPAQ-SF, PAR-Q, and friendship measures) [29, 30, 31, 32, 33]. The experimenter demonstrated the standing triceps pulldown, helped participants select an appropriate resistance load, and supervised familiarization trials. Participants then played a single-player calibration round to collect baseline motion data, followed by the six experimental conditions. After each condition, participants completed the Flow Short Scale and Intrinsic Motivation Inventory [34, 35, 36, 37].

Participants. We recruited 36 participants; 30 completed both sessions (14 female, 15 male, 1 non-binary; age 19–32, $M = 24.7$, $SD = 3.2$). Eligibility required age ≥ 18 and PAR-Q clearance [31]. Participants received a supermarket voucher (\$ ∼20) per session. All procedures were approved by the institutional ethics committee.

Measures. We logged objective performance (movement score, movement duration, repetition frequency, and total repetitions). Subjective measures included IMI and Flow Short Scale after each condition [34, 35, 36, 37], personality via BFI-10 [29], and friendship quality/background measures (McGill Friendship Questionnaire, FQS-Conflict, demographics, exercise/VR background, IPAQ-SF, and PAR-Q) [32, 33, 30, 31].

5. Results

All quantitative analyses were conducted with $N = 30$. To make the linkage between our research questions and outcomes explicit, we report results in three blocks. First, to answer RQ1, we test the effects of Mode and Feedforward Target (and their interaction) on objective performance (MeanScore, MeanDur, Freq, TotalPulls) and self-reported experience (IMI, Flow). Second, to address RQ2, we summarize personality-related effects from linear mixed models on motivation and experiential measures. Third, we report exploratory moderation patterns involving friendship quality in friend-targeted play to inform RQ3 and RQ4 (treated as hypothesis-generating due to sample size and multiple comparisons).

We conducted repeated-measures ANOVAs to examine the effects of Mode (competition vs. cooperation) and Feedforward Target (self, friend, stranger) on performance outcomes (MeanScore, MeanDur, Freq, TotalPulls). To complement objective logs, we analyzed participants' self-reported experiences using the Intrinsic Motivation Inventory (IMI) and the Flow Short Scale.

Primary Results.

Table 1
Summary of significant personality effects from linear mixed models. Only non-intercept effects that survived within-DV FDR correction are shown. Arrows indicate direction of effect.

DV	Extraversion	Agreeableness	Conscientiousness	Neuroticism	Openness
IMI-Interest					
IMI-Effort		Stranger↓; Stranger×A↑			
IMI-Pressure		A↓	Coop↓; Coop×C↑		
IMI-Competence		Stranger↓; Coop×Stranger↑; Stranger×A↑; Coop×Stranger×A↓	C↑	N↓	
Flow-Total		Coop×Stranger×A↓			O↓; Self×O↑
Flow-Worry	Stranger↓		Coop×Stranger↓	Self×N↓	
Flow-Fluency		Coop×Self↑; Coop×Stranger↑; Coop×Self×A↓; Coop×Stranger×A↓			
Absorption					Self↓; Self×O↑

Movement score. A strong main effect of Mode was found, $F = 39.53$, $p < .001$, $\eta_p^2 = .83$, $\omega^2 \approx .81$. Participants produced more consistent movements in competition than in cooperation. No significant effect of Target, $F = 0.28$, $p = .716$, nor a Mode × Target interaction, $F = 0.11$, $p = .820$, was observed.

Total repetitions. A significant main effect of Mode emerged, $F = 8.29$, $p = .021$, $\eta_p^2 = .51$, $\omega^2 \approx .45$, indicating more repetitions in competition than in cooperation. Neither the main effect of Target, $F = 1.04$, $p = .371$, nor the interaction, $F = 0.17$, $p = .804$, was significant.

Repetition frequency. The Mode × Target interaction was significant, $F = 6.83$, $p = .008$, $\eta_p^2 = .46$, $\omega^2 \approx .41$. Follow-up comparisons suggested that frequency patterns varied across friend, self, and stranger depending on whether participants competed or cooperated, although no individual pairwise contrast survived Bonferroni correction.

Motivation. A significant main effect of Target was found for Interest/Enjoyment. Participants reported greater enjoyment when playing with a friend ($M = 41.42$, $SD = 6.93$) compared to a stranger ($M = 37.52$, $SD = 8.28$), $t(29) = 4.09$, $p = .0003$, Bonferroni-corrected $p = .00094$, $d \approx 0.50$. In competition, friend was higher than stranger, $t(29) = 2.80$, $p = .009$, Bonferroni-corrected $p = .027$, $d \approx 0.46$. In cooperation, friend was higher than stranger, $t(29) = 2.66$, $p = .013$, Bonferroni-corrected $p = .038$, $d \approx 0.44$. The other IMI and Flow scales showed no reliable effects of Mode or Target after correction.

Answer to RQ1. Competition improved movement quality (MeanScore) and total repetitions, whereas target identity primarily affected affect: friend targets increased Interest/Enjoyment relative to strangers across both modes; pacing (Freq) showed a qualified Mode×Target interaction.

Individual Differences. After within-DV FDR, only a small set of personality effects remained (Table 1). Conscientiousness was linked to higher competence ratings, and Neuroticism was related to lower competence. Openness related to lower flow was partly mitigated when targeting the self. Agreeableness selectively moderated stranger and cooperation effects on effort, competence, flow, and fluency.

Answer to RQ2. Personality traits showed selective associations with experience: conscientiousness predicted higher perceived competence, neuroticism predicted lower competence, and openness related to lower flow with partial mitigation under self-targeting; agreeableness moderated several outcomes in stranger and cooperative contexts.

Exploratory moderation patterns (friendship context).

When asked to indicate their favorite game version, 20 participants (67%) preferred cooperative play, while 10 (33%) preferred competition. Target preferences were 21 participants favoring a friend, 5 favoring self, and 1 favoring a stranger (missing $n = 3$). Romantic dyads reported higher competence, flow, and fluency during cooperation.

Qualitative Insights. Open-ended responses explain the quantitative pattern. Competition mobilized execution with higher movement quality and more repetitions, while friend targets typically lifted enjoyment relative to strangers.

Answer to RQ3 and RQ4 (exploratory). We observed preference patterns consistent with friendship playing an affective role (most participants preferred friend targets), and relationship context (e.g., romantic dyads) coincided with higher competence/flow in cooperation; these signals motivate preregistered, higher-powered tests of friendship-quality × personality × mode interactions.

6. Discussion

This work-in-progress examines social augmentation for resistance training in VR by factorially varying social mode (competition vs. cooperation) and social feedforward target (self, friend, stranger) within a single cable-machine exergame. Our results suggest that "social" is not a monolithic feature: different social levers shaped movement performance versus affective experience in distinct ways, and a small set of individual-differences effects points to opportunities for empathic personalization.

6.1. Mode and identity act through separable pathways in resistance VR

Our primary analyses show a consistent dissociation. Mode robustly shaped movement outcomes: competition produced higher movement quality (MeanScore) and more repetitions than cooperation, with no reliable Mode×Target interaction for MeanScore or TotalPulls. In contrast, target identity mainly tuned affect: the only reliable subjective difference after correction was higher Interest/Enjoyment with a friend target compared to a stranger, across both competition and cooperation. Taken together, our data support two relatively independent "dials" for social augmentation in resistance VR: a performance dial (mode) and an engagement-climate dial (identity).

This separation is practically important in resistance training where technique and perceived safety are central; here we operationalize movement quality using a repetition-level similarity-and-smoothness metric (MeanScore). Competitive framing can be deployed as a short "execution-consistency block" to improve movement quality as operationalized by our MeanScore metric and to increase repetitions, while friend-based targets can be used to sustain enjoyment without measurably changing kinematics. The pattern is consistent with prior work showing that competitive or comparative contexts can increase effort and performance in exergames [16, 15], while socially meaningful targets can elevate intrinsic motivation in feedforward designs [13]. Notably, our results extend these insights into a high-load, cable-based resistance task, complementing prior feedforward work largely evaluated in aerobic or cycling-style exergames [11, 12].

6.2. A qualified interaction: frequency depends on mode–target pairing

We observed a significant Mode×Target interaction for repetition frequency, yet no individual pairwise comparison survived Bonferroni correction. We interpret this as an early signal that pacing strategies may be more sensitive to social configuration than gross outcomes such as total repetitions or movement quality. In practice, pacing is a plausible channel for social augmentation: in competitive contexts, players may stabilize tempo to maintain consistency, whereas in cooperation pacing may be negotiated implicitly (or destabilized) by shared goals and attention. This motivates future work to include manipulation checks and pacing-relevant instrumentation (e.g., explicit tempo cues, timing windows, or adaptive ghost speed) to clarify whether social mode and identity systematically shape tempo regulation in resistance VR.

6.3. Social augmentation is not uniformly "gentle": cooperation can be preferred yet effort-mobilizing

Preference data add nuance. Although competition improved movement quality and repetitions, two-thirds of participants reported preferring cooperation, and most preferred friend targets over self or stranger. This aligns with the idea that perceived value of social augmentation is not solely determined by objective performance gains. In our open-ended responses, participants described competition as focusing execution (consistent with the observed MeanScore and TotalPulls advantages), while cooperation was often described as socially rewarding. This highlights a recurring design tension in social XR: systems may optimize for technique and output (where competition helped), yet users may gravitate toward experiences that feel socially supportive or meaningful (where cooperation and friend identity were preferred) [15, 16].

A practical implication is to provide sequencing rather than choosing one mode: brief competitive bursts for technique tuning, then cooperative phases for social satisfaction and variety. This respects both the performance evidence and users' stated preferences.

6.4. Individual differences: signals for empathic personalization, not prescriptions

After within-DV FDR correction, personality effects were selective, suggesting that personalization should be lightweight and opt-in rather than rule-based. The most consistent pattern was that conscientiousness related to higher competence while neuroticism related to lower competence.

Openness showed a more contextual pattern: it related to lower overall flow, but self targets partially mitigated this. Agreeableness selectively moderated stranger and cooperation effects across several experiential outcomes.

The key takeaway is that resistance VR may benefit from relationally- and trait-aware defaults. Rather than inferring stable "best" pairings, systems can use small amounts of information to offer empathic controls: for example, defaulting to friend targets for enjoyment, offering self targets as an autonomy-oriented practice mode, and using stranger targets sparingly with competence-preserving scaffolds. These ideas align with broader claims that social and motivational mechanisms in exergames depend on context and comparison targets [15], and that social feedforward can be particularly motivating when anchored in a meaningful relationship [13].

6.5. Agenda for adaptive, ethical social feedforward in strength training

Grounded in the above results, we propose four directions for community discussion:

(A) Sequence modes by training goal. Use short competitive blocks when technique and repetition quality are priorities, then transition to cooperative or private blocks for recovery and social satisfaction.

(B) Use identity primarily for affective tuning. Friend targets are a sensible default for enjoyment; self targets can support autonomy and may benefit users whose flow depends on self-referential goals; stranger targets should be optional and scaffolded.

(C) Make social augmentation legible and controllable. Because social configurations can change pressure and competence for some users, provide clear controls for identity visibility and comparison timing, and communicate what the ghost represents and how its data are used.

(D) Move beyond non-reactive ghosts. Our prototype uses replay-based targets. Future iterations should explore semi-reactive or adaptive feedforward that stabilizes pacing and challenge without increasing evaluative pressure, and test whether these mechanisms support adherence over time.

6.6. Limitations

This study examined a single isolation exercise in a controlled lab context and did not include a conventional-training baseline or a non-social VR baseline. Target identity was achieved via replay ghosts; without ability matching, friend–stranger differences may partially reflect difficulty differences rather than identity alone. The movement-quality feedback shown in-game was derived from the same metric used in analysis, motivating future validation against coach ratings, external kinematics, or physiological measures. Finally, individual-difference findings rely on a brief personality inventory (BFI-10) and a modest sample, so they should be treated as exploratory signals that motivate larger confirmatory studies.

7. Conclusion

We presented a VR cable-machine exergame with two controllable design levers—social mode and social feedforward target—that were largely separable for key outcomes, while pacing showed an interaction signal, and evaluated them in a within-subjects 2×3 study. Competition improved movement quality, as measured by MeanScore, and increased repetitions, while target identity primarily shaped affect: friend targets increased Interest/Enjoyment relative to strangers, without measurably changing kinematics. A qualified Mode×Target interaction emerged for repetition frequency, suggesting that pacing may be a sensitive channel for future adaptive designs. Exploratory analyses indicated selective moderation by personality traits and friendship dimensions, motivating individual-differences-aware social augmentation.

Our contribution is a resistance-training case in which safety-relevant movement quality is central, paired with evidence that social design choices can be decomposed into performance and affect pathways. We argue for adaptive social feedforward that sequences competitive and cooperative blocks by training goal, defaults to friend-based targets for engagement, offers autonomy-supportive self targets, and treats stranger contexts as scaffolded and optional. We hope this work can seed broader discussion on ethical, controllable, and context-sensitive social augmentation in XR, and serve as a foundation for a longer-form submission after the workshop.

Declaration on Generative AI

The authors have not used any Generative AI tools.

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