Adaptive Training in Virtual Reality Through Dynamic Alien Motion Support

Vittorio Fiscale
Computer Science Department
University of Torino
Torino, Italy
vittorio.fiscale@unito.it

Tetsunari Inamura
Brain Science Institute
Tamagawa University
Tokyo, Japan
inamura@lab.tamagawa.ac.jp

Agata Marta Soccini
Computer Science Department
University of Torino
Torino, Italy
agatamarta.soccini@unito.it

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***Abstract*—Serious games in virtual reality showed promising results when applied to medical therapy, both improving the motivation of the patients, and the outcomes of the training processes. This technology allows operators to have full control over the virtual environment, as well as over the virtual bodies of the users. An alien motion, i.e. an alteration of the simulation response to the actions of the users, can be introduced to provide them with false feedback about their performance without them being aware of it. These modifications can be adjusted to support them during the training by making them believe they are performing better than they are in the physical world. The goal of this project is to investigate in which extent the support influences the outcomes of a virtual training. In this work, we present a ball throwing virtual scenario in which users are assisted through alien motion. Our findings show that dynamically supporting people can have a positive impact on the outcomes.**

***Index Terms*—Virtual Reality, Training, Alien Motion, False Feedback**

I. INTRODUCTION

Virtual Reality (VR) is a technology that immerses the user in a fully synthetic environment. These simulations can provide users with sensory feedback, creating the illusion of being in the virtual world [1]. This feeling is called sense of presence and, together with immersion and interactivity, it forms the three main characteristics of VR [2]. In the context of health, this technology can be applied in the form of VR games. These are designed to promote the learning of skills related to physical and cognitive functions, as well as to encourage positive behaviour in players. They typically use tasks such as puzzles, repetitive exercises or exploration of virtual environments [3]. Several studies showed that the use of VR serious games and exergames for health is promising in various areas. These include physical and neuro-cognitive rehabilitation [4]–[6], anxiety [7], pain [8] and phobias treatments [9]. A VR simulation can improve the rehabilitation process by providing a highly interactive and immersive experience [10], bringing, among others, the following benefits:

- Large amounts of objective data can be acquired through sensors and analyzed to monitor rehabilitation progress [11]. This reduces the need for direct supervision by the therapist, allowing a caregiver to supervise the session alone [12];
- Cognitive rehabilitation can be more enjoyable and can take advantage of game-related elements and mechanics to motivate patients and increase their participation in the treatment [13];
- The exercises' difficulty level and intensity can be adjusted according to the patients' needs [10];
- VR provides a sustainable solution by reducing resource consumption and promoting remote training [14], [15].

One way to enhance motivation during rehabilitation training is to provide users with false feedback [16], i.e. to inform them that their performance levels are better or worse than they actually are [17]. VR enables operators to fully control the virtual environment, allowing them to alter the visual feedback perceived by the user [18]. In a virtual training process, it is possible to provide false feedback on user performance by introducing alien motion, i.e. the modification of the behaviour of virtual elements, including the user's avatar, objects and actions [19]–[22]. The goal of our research is to propose and validate a new methodology to enhance a rehabilitation process by using VR technology. The research question that drives our work is the following:

- **RQ.** How can the outcomes of a virtual rehabilitation process be improved?

Our idea is to support users through alien motion without their awareness and provide them with positive false feedback to improve their training outcomes and their psychological state. This work is part of wider study on how these alterations influence 1) the users' perceived control in the virtual environment, 2) confidence in their abilities and 3) their training performance levels. Preliminary analysis indicates that the introduction of alien motion does not affect the participants' perception of being the ones producing actions in the simulation [23]. In this paper, we present some encouraging early findings about the influence of this support on training outcomes. This methodology could be applied to health games as well as other contexts, as long as the goal is to learn or train skills or behaviours. These contexts may include sports, education, or safety training.

II. RELATED WORKS

Several works explored the effects of altering the users' avatar in a VR simulation. Soccini *et al.* [19]–[22] investigated the reaction of the real body after the introduction of alien

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motion in the virtual hand. The results suggested that it did not lead to a decrease in the users' perceived control and it induced finger movements, leading to specific postures. Shum *et al.* [24] developed a VR training system for upper limbs rehabilitation. This process involves using both upper extremities together to recover the more affected limb. In this experiment, error augmentation was used, a technique that consists in amplifying errors according to the goal to be achieved, without the user being aware of it. During a two-handed grasping task, the error of the most affected hand was amplified so that the user tried to correct it. Compared to unmodified feedback, the exaggeration of the error led to an improvement in the asymmetry error. According to Bourdin *et al.* [25], modifying the visual feedback during the movement of a virtual avatar's arm can lead to unconscious motor adjustments in the real arm. During the investigation, participants were asked to perform 90° elbow flexions while stretching an elastic band. The visual feedback displayed three distinct scenarios by reproducing the same movement, a wider movement or a tighter one. The results showed that the last two conditions verified respectively smaller and larger real movements than those performed in the first condition, moreover only three out of 27 participants noticed the virtual arm movement alterations. Although the introduction of avatar modification looks promising in improving training outcomes, to the best of our knowledge, the effects of modifying the behaviour of the virtual elements with which users interact are still unknown.

III. TRAINING SYSTEM

To test our assumptions, we developed a VR training system that allows users to practice a visuomotor task: attempting to hit a target by throwing a ball. However, users are not informed that this system can change the trajectory of the projectile and improve their performance. This investigation aims to determine whether or not individuals who receive such support achieve better results than others. To make the experience fully immersive and isolate the user from the real world, we decided to use an Head-Mounted Display (HMD), the HTC Vive Pro[1]. The latter was selected as it allows to track body parts other than hands by using trackers placed at specific points. In addition to the HMD, the user must also wear 2 Vive trackers[2], one for the dominant hand and one for the dominant shoulder, and 1 Vive controller[3] held in the the non-dominant hand. Figure 1 shows the hardware worn by a user during throwing action. We used Unity[4] 2021.3 to develop the VR system and Python[5] version 3.12.1 for data analysis. The training system we developed immerses users in a fully synthetic environment and allows them to practice a simple visuomotor skill: target shooting. They have to hit the centre of a target by launching a ball as many times as possible. Within the simulation, users must perform the following workflow:

Fig. 1: User while performing the throwing action.

- Grab the ball by pressing a button on the Vive controller;
- Throw the ball by performing a bottom upwards movement with the dominant hand while holding the Vive tracker.

The ball will be released on fulfilment of several conditions related to direction and velocity of the launch. The angle between the shoulder vertical vector and the shoulder-hand vector must be greater than 45° and oriented in the forward direction of the user. Furthermore, the Vive hand tracker's velocity magnitude must be greater than $1.5 m/s$. Figure 2 illustrates the user's view after releasing the ball.

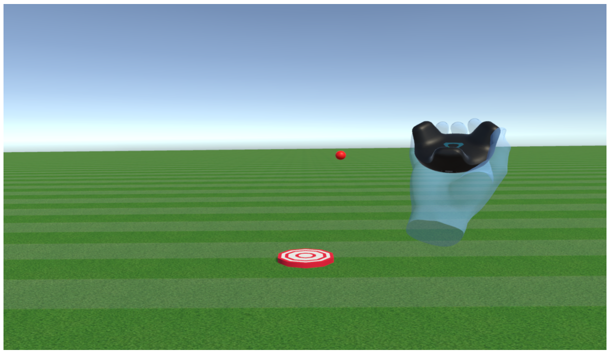

Fig. 2: User's view after the ball releasing.

As previously mentioned, upon the release, the ball's velocity can be altered by the system without the user's awareness. When this happens, the ball will follow a better trajectory than the original one, resulting in it landing closer to the target. At the same time, the real trajectory is computed so that the information about the users' actual performance is preserved. This alteration occurs by calculating a linear interpolation between the original velocity provided by the user's movement and the target velocity to hit the target's centre. The result is an enhanced velocity that will be assigned to the visible ball at the moment of release. Our proposal consists in adapting the support amount in real-time according to the users' recent performances. They will only receive support when necessary,

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[1] https://www.vive.com/eu/product/vive-pro/

[2] https://www.vive.com/nz/accessory/vive-tracker/

[3] https://www.vive.com/eu/accessory/controller2018/

[4] https://unity.com/

[5] https://www.python.org/

preventing them from being exposed to repeated failures. To investigate the effectiveness of this strategy we conducted an experiment in which we tested three support management approaches:

- **No support at all:** no support is provided for the whole duration of the virtual training and the original and enhanced velocities coincide;
- **High static support:** the user is provided with an high and constant support for a whole training session. The improved velocity is exactly halfway between the original and the target one.;
- **Dynamic support:** this method represents our proposal and it consists in adapting the amount of support according to the average accuracy of the last ten shots. If the performances are good, the support is reduced. Otherwise, it will be increased.

IV. EXPERIMENT

A. Overview

To test the three different approaches, we conducted an experiment on 30 participants, divided in three groups of 10 users each:

- **Group A:** were not subjected to any support;
- **Group B:** were exposed to high static support;
- **Group C:** were subjected to dynamic support.

None of the three groups were warned about the presence of the support. The requested task was the same for all users: try to hit the center of the target as many times as possible. Each participant had to go through four sessions:

- **Session 0:** warm-up session, the goal is to make the user familiarize with the virtual environment and the launch mechanic. In this session the support is null for all groups;
- **Session 1:** the aim of this session is to assess the initial skill level of the user. Also in this session the support is null for all groups;
- **Session 2:** the longest training session in which users of groups B and C are subject to static and dynamic support respectively;
- **Session 3:** last session, necessary to evaluate the final skill level reached by the user. The conditions in terms of length and support are the same as in session 1.

The 4 sessions differ in the number of shots. Session 2 is the longest (50 throws) as we wanted the users to train for longer under the influence of the three support strategies. Session 1 and 3 have the same number of throws (30) so that the initial and final skill level can be compared more easily. Table I shows the number of throws for each session of the experiment.

TABLE I: Number of shots of each session.

Session 0	Session 1	Session 2	Session 3
10	30	50	30

B. Evaluation metric

The system can collect data on both altered and original performances. To assess the users' skill level variation during the training, we observed the number of successful hits out of the total number of throws. We only considered the unaltered trajectory because it represent the real performance of the user. We defined the hit rate as the percentage of successful shots out of the total number of attempts made by the user within a session. To calculate the hit rate HR_s for session s, we used the following formula:

$$HR_s = \frac{\textit{successful shots in session s}}{\textit{shots attempted in session s}} * 100$$

To calculate the hit rate $HR_{g,s}$ of a group g in session s, we computed the arithmetic mean of the hit rates of all users in group g in session s. However, using only the variation between the group average hit rate does not provide an accurate assessment of individual skill level variation from session 1 to session 3 for each user. For this reason, we defined the hit rate percentage change $HRPC$ as:

$$HRPC = \Big(\frac{HR_3 - HR_1}{HR_1}\Big)*100$$

It represents the percentage change between the hit rate in session 1 and the hit rate in session 3, and it is calculated for each user. The $HRPC_g$ of a group g is the arithmetic mean of the $HRPC$ of all users in that group. This allows for an assessment of the group's performance improvement while considering the different starting skill levels of the users. In addition to the arithmetic mean, we also calculated the median for these two metrics to prevent extreme values from having too much impact on the evaluation.

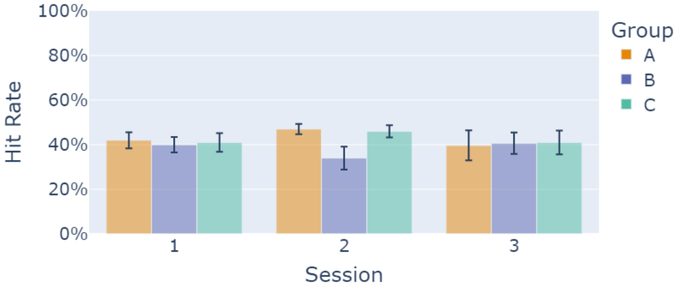
C. Support strategies

As mentioned before, the system can enhance the trajectory of users' throws to prevent repeated failures and maintain their confidence in their capabilities. Conducting training within a virtual environment enables real-time control over the frequency and amount of support provided by the system. We believe that assistance should be adaptive, based on the participants' recent performance. We evaluated, by using the previously described evaluation metrics, the approaches mentioned above: no support, high static support and dynamic support.

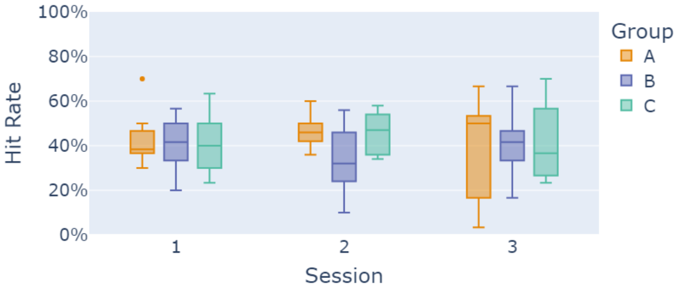
V. RESULTS

Below we show the results of some preliminary analysis evaluating the average hit rate of the groups in the different sessions and its percentage variation from session 1 to 3. In these analyses, we excluded session 0 as it was a warm-up session. Figure 3a shows the average hit rate ($HR_{g,s}$) for each group across sessions. We observe that in session 1, under the same conditions (zero support), group A had slightly higher results in terms of hit rates. In session 2, support for groups B and C was introduced, with very different results. Group B, with static support, suffered a marked deterioration

(-6%), while group C, with dynamic support, improved its performance ($+5\%$). Group A also improved in the second session. The differences between the performance of the supported and unsupported groups started to appear in the last session. Compared to the initial level of skill, group A was the only one to obtain a lower score, while Group C returned to the initial level. Group B, on the other hand, was the only one to slightly increase its average skill level. Figure 3b displays the distribution of the average hit rates of users in each session. For low hit rates, Group A showed a progressive increase in variability, while Group C followed the opposite trend. Table II shows all the data concerning the hit rate $HR_{g,s}$ of all groups across sessions.



(a) Hit rate mean and standard error of the mean for each group across sessions.



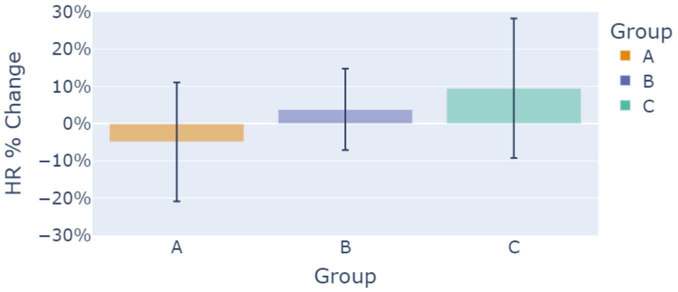
(b) Hit rate median and distribution for each group across sessions.

Fig. 3: Hit rate evaluation charts.

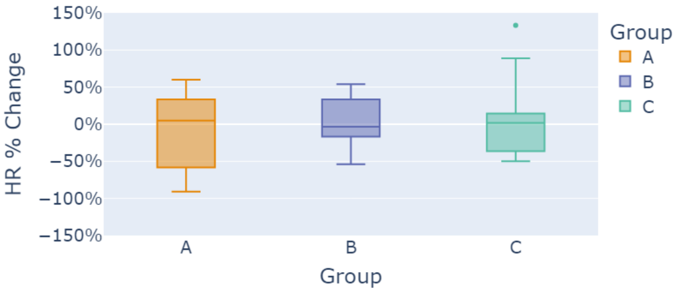
TABLE II: Hit rate mean, standard error of the mean, and median for each group across sessions.

Group	Session	$HR_{g,s}$	$HR_{g,s}$ Sem*	$HR_{g,s}$ Med**
A	1	42.00%	3.62%	38.33%
	2	47.00%	2.31%	46.00%
	3	39.67%	6.73%	50.00%
B	1	40.00%	3.48%	41.67%
	2	34.00%	5.14%	32.00%
	3	40.67%	4.81%	41.67%
C	1	41.00%	4.16%	40.00%
	2	46.00%	2.76%	47.00%
	3	41.00%	5.31%	36.67%

*Sem: standard error of the mean
**Med: median



(a) Hit rate percentage change mean and standard error of the mean for each group.



(b) Hit rate percentage change median and distribution for each group.

Fig. 4: Hit rate percentage change evaluation charts.

However, as mentioned above, this metric does not take into account the personal improvements of different users, so we evaluated the average hit rate percentage change $HRPC_g$ from session 1 to 3 for each group g (see Figure 4a). Only group A experienced a decline in performance(-4.90%). On the other hand, users who received dynamic support experienced the greatest improvement, with an average positive change of $+9.52\%$. Group B also showed improvement ($+3.83\%$), although less than group C. However, the $HRPC$s of groups A and C were more variable than those in group B. The distributions of users' $HRPC$ confirm these results (see Figure 4b). Group C showed smaller decreases compared to groups A and B, while exhibiting high variability in positive changes. Table III shows all values related to the $HRPC$ metric.

TABLE III: Hit rate percentage change mean, standard error of the mean, and median for each group.

Group	$HRPC_g$	$HRPC_g$ Sem*	$HRPC_g$ Med**
A	-4.90%	15.99%	+4.76%
B	+3.83%	10.94%	-3.33%
C	+9.52%	18.73%	+1.71%

*Sem: standard error of the mean
**Med: median

VI. DISCUSSION AND CONCLUSIONS

We developed a VR target shooting training system that can alter the projectile's trajectory to assist users. We tested three different support approaches: 1) no support, 2) high static support, 3) dynamic support and our findings were encouraging. For both metrics hit rate and hit rate percentage change, the unsupported users were the only ones to perform worse in the last session compared to how they started. Dynamic support seemed to be far superior to the other two methods in the second evaluation metric. Also, it was the only approach that improved both mean and median in hit rate percentage change. These results suggest that providing support during a virtual training process without the user's knowledge could promote developing skills. Furthermore, providing support only when it is needed seems to foster greater improvements. The high static support lowered the average hit rate when it was introduced, probably because people learned to shoot with a good velocity to hit the target with the altered ball, but not enough with the actual throw. Nevertheless, on support removal, group B users were able to slightly exceed their initial skill level. Under support, users may have increased their confidence in their abilities, leading to improved performance. The unsupported and dynamically supported users performed very similarly, but by the end of the experiment only the latter were able to improve from session 1 to session 3. To determine the relationship between performance and confidence in users' abilities, we plan to investigate the influence of support on self-efficacy. This support system could be integrated into VR health games to facilitate patient training and enhance its outcomes. Although the results are encouraging, these tests were conducted on a limited number of users and it would be useful to extend the study to more participants.

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