Evaluation of multimodal feedback effects on the time-course of motor learning in multimodal VR platform for rowing training

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Abstract *This study focused on the benefits of feedback augmentation for multi-session training of a complex motor-cognitive skill of indoor rowing in virtual environment. Specifically, we compared the effectiveness of augmented information feedback provided per training trial either visually, haptically or visual-haptically to the non-augmented condition, where no on-line feedback on task performance was afforded during training sessions. Surprisingly, the non-augmented training group was in general as successful in the long-term learning of a rowing skill as the augmented groups and according to some measures even superior to them. Our results also highlight important differences in the course of learning and skill representation upon different feedback conditions provided during training and may provide useful insights to the optimization for both sport and rehabilitation training protocols in VR.*

Keywords *indoor rowing, long-term training, augmented feedback, visual feedback, haptic feedback, motor learning, skill acquisition, VR*

I. INTRODUCTION

Teaching complex ecological motor tasks in rehabilitation as well as in sports, requires knowledge of how to accurately guide clients during training sessions. Unguided experience and spontaneous practice by trial and error of a given task, as well as deficient monitoring of self-performance, absence of feedback and knowledge of results, may lead to inferior learning and poorer performance [1, 2]. Rowing is a periodic and constrained multi-faceted skill that requires high levels of consistency, precision and smoothness of stroke [3]. Indoor rowing is thus an excellent activity for developing or regaining physical fitness and a highly accessible form of exercise, allowing a non-impact and non-load bearing environment for cross-training and rehabilitation. As other procedural skills, rowing competencies evolve through long practice inducing brain plasticity and can benefit from simulator empowered by virtual reality (VR) technologies. Currently, most VR simulators are mimicking ecological tasks using similar to natural feedbacks to promote acquisition. However, there is no evidence that information available in the real world affects the course of skill learning in the same way in the VR environment as in ecological setting. Therefore, the necessity in keeping high fidelity between ecological to virtual task feedback designs should be questioned. Here, we investigated, using a simplified platform of indoor rowing designed to provide concurrent visual and haptic feedbacks, how learning of rowing hand movements' trajectories is affected by presence and type of augmented information feedback afforded. Learning in non-augmented group was compared to three feedback augmented groups: Visual, Haptic and Visual-Haptic. Data were analyzed in terms of accuracy of performance (error & variance) & shape of the hand trajectory proportions.

II. METHODS

31 healthy young male adults naïve to the rowing task were trained to perform a specific spatial-temporal pattern of movements of a rowing handle (held with two hands). The movement pattern is derived from the analysis of expert's movements requires during each strike to move through three transition points in space (A - catch, B - finish and C - start of recovery) repeatedly, smoothly and as accurately as possible, according to the externally cued pace of 15SPM (strikes per minute) provided by a metronome (Fig.1). Training included 5 sessions separated 1-2 days apart. The setup included Concept2 indoor rowing ergometer, LCD screen, two Vicon motion capture cameras for tracking ergometer's handle, airflow haptic system and a metronome.

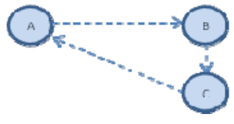
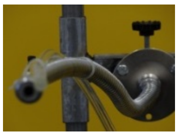
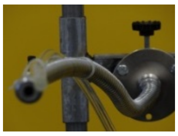


Figure 1: Trained rowing pattern: hands movement is from A - catch, to B - finish and to C - start of recovery. Points A, B and C were individually defined to account for height and hand length

The experimental groups were segmented to non-augmented group and feedback augmented groups (Table 1). Participants were randomly assigned to one of the four groups. All participants were trained in front of the screen with a scenic sea view which presented the progress of the boat according to the pace of strikes.

Table 1: Description of study groups

Group	Display	Haptic device	Description
Non-augmented training (N=7)			*Scenic background. No augmented information feedback on performance*
Visual (N=9)			*Visual feedback provided by dynamic color bars, representing the location of A, B & C points in space on the boat background. At the end of each strike color of the bars changed to red or green indicate accuracy of movement through A, B & C respectively. Direction of error was shown by*
Haptic (N=9)			*Haptic feedback provided by airflow markers pointing for respective locations of the A, B & C points in hands space*
Visual & Haptic (N=7)			*Combined visual-haptic feedback: dynamic color bars, representing the location of A, B & C on the boat background + haptic markers for location of the A, B & C points in hands space.*

III. RESULTS

Data were analyzed according to mean group accuracy measures (error & variance) & shape proportions. Error was defined by summation of the distance (=error) of hand movement from the desired transition points A, B, C. Variance, which served as indication for consistency of repetitive performance during training blocks, was calculated according to the standard deviation of the error. Shapes of handle trajectories were analytically classified to four types: Triangle, Ellipse, Drop, Other. Then, for each individual participant dominant shape was determined and group analysis on predominant shape was performed.

Our results indicate that the non-augmented training group was as successful in acquisition of rowing as the augmented groups and by the last training session all groups showed similar learning in terms of errors rates (Fig.2). Group*day significant interaction ($P<0.038$, $F=2.3$) revealed that the high levels of variance and error originated from the 3rd day increases and was followed by a decrease to similar levels of error and variance as in the feedback groups by the 4-th day of training. In the feedback groups there was a continuous decrease in variance of performance, presumably due to fixation of strategy according to the augmented enhancer [4], whereas in the non-augmented group changing strategies [5] were reflected also in the highest mean error & variance levels across the training days (Fig.3). All study groups showed increase in triangle proportions (supporting accuracy), during the non-augmented trials (Fig.4). The type of augmented enhancer affected the preferred (dominant trajectory shape) - both groups with Visual feedback that improved primarily on the accuracy of trajectory, showed also relative highest increase of the triangular trajectories. Furthermore, the non-augmented group was the only group that had a significant increase ($P<0.006$, $F=6.8$) in drop proportions (Fig 6), also defined as the preferable shape trajectory by expert rowers [5, 6]. Non-augmented group also showed overall decrease in errors, indicating spontaneous, non-guided long-term learning of preferred movement patterns in rowing.

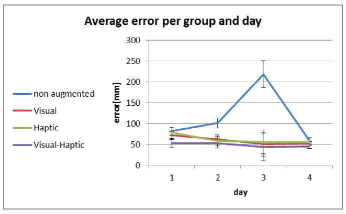


Figure 2: average error per training day

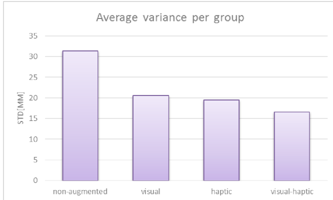


Figure 3: average variance per group

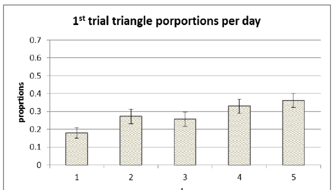


Figure 4: average triangle proportions

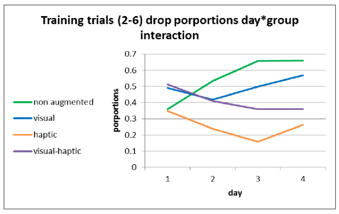


Figure 5: drop proportions per group

To conclude, our results highlight the similarities and the differences of training on a rowing skill upon different feedback conditions and may provide useful insights to the optimization of training protocols in VR [3].

ACKNOWLEDGMENT

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