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Full Length Article

Performance of a visuomotor walking task in an augmented reality training setting

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ABSTRACT

Visual cues can be used to train walking patterns. Here, we studied the performance and learning capacities of healthy subjects executing a high-precision visuomotor walking task, in an augmented reality training set-up. A beamer was used to project visual stepping targets on the walking surface of an instrumented treadmill. Two speeds were used to manipulate task difficulty. All participants (n = 20) had to change their step length to hit visual stepping targets with a specific part of their foot, while walking on a treadmill over seven consecutive training blocks, each block composed of 100 stepping targets. Distance between stepping targets was varied between short, medium and long steps. Training blocks could either be composed of random stepping targets (no fixed sequence was present in the distance between the stepping targets) or sequenced stepping targets (repeating fixed sequence was present). Random training blocks were used to measure non-specific learning and sequenced training blocks were used to measure sequence-specific learning. Primary outcome measures were performance (% of correct hits), and learning effects (increase in performance over the training blocks: both sequence-specific and non-specific). Secondary outcome measures were the performance and stepping-error in relation to the step length (distance between stepping target). Subjects were able to score 76% and 54% at first try for lower speed (2.3 km/h) and higher speed (3.3 km/h) trials, respectively. Performance scores did not increase over the course of the trials, nor did the subjects show the ability to learn a sequenced walking task. Subjects were better able to hit targets while increasing their step length, compared to shortening it. In conclusion, augmented reality training by use of the current set-up was intuitive for the user. Suboptimal feedback presentation might have limited the learning effects of the subjects.

1. Introduction

Gait training on a treadmill is often not experienced as an engaging activity, since subjects (both healthy and patients) usually do not have to pay much attention during steady walking (Mazaheri et al., 2014). A popular method to increase the motivation of the user is adding explicit goals (targets/games) to the training environment, using computer-generated environments. Two types of computer-generated environments can be distinguished: virtual reality and augmented reality. The first is already widely applied in

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training situations and the second is increasing in popularity. Virtual reality creates an artificial environment, where the visual representation is separated from the physical walking environment and the user solely interacts with the computer-generated world rather than with the real world. In training situations, this is often done by the use of a motion capture system that records body movements and displays these on a screen by using an animation (Adamovich, Fluet, Tunik, & Merians, 2009). Augmented reality integrates computer-generated elements within the real world. The visual representation is incorporated into the physical walking environment and the user interacts with the real world, which is overlaid with computer-generated elements. For example, by using beamers or other projection systems that project visual objects on an instrumented treadmill. Movements of the user directly interact with the game, without interference of a motion capture system or a screen in front of the user.

Visual feedback presented by both types of computer-generated environments (virtual reality as well as augmented reality) positively contributes to learning motor tasks (Darekar, McFadyen, Lamontagne, & Fung, 2015; Lange et al., 2010). They can be used to manipulate training-context, thereby influencing context-specific learning and promoting transfer of learning to other situations (Kloter & Dietz, 2012; McVea & Pearson, 2007). van Diest, Lamoth, Stegenga, Verkerke, and Postema (2013) investigated the use of virtual reality for balance improvements in elderly and found positive training results due to an increased motivational component compared to regular training. Choi, Jensen, and Nielsen (2016) used a virtual reality training set-up to show that visual feedback can be used to improve sequence learning. In particular, the results of the study implicate that by use of this training set-up, sequence learning can be integrated with a highly automatic task such as walking, even over a relatively small period of only 300 steps. In a virtual reality set-up, proprioceptive information needs to be remapped to what is seen on a screen. The results by Choi et al. therefore also showed a non-specific learning curve, as subjects increased on task performance throughout the course of the experiment. We hypothesize that augmented reality might be more intuitive to the user on this aspect, as the real world is already integrated in the training set-up. Several studies (Fonteyn et al., 2014; van Ooijen et al., 2015) have demonstrated that augmented reality training can successfully be used for gait adaptability training in various patient groups. The results show that after a period of training in such an environment, subjects are better able to modulate their steps to the environment. However, contrary to the virtual reality environment, the effects of (sequenced) locomotor learning in an augmented reality training environment, have yet not been presented in literature. Performing such a study improves our knowledge on the performance and learning capacities (either non-specific or sequence specific) of subjects in relation to such a training set-up. This knowledge might ultimately lead to a better understanding of the different computer-generated environments, their applicability in training situations, and might thereby contribute to the improvement of training programs.

The goal of this paper is therefore to study locomotor performance and learning capacities as a result of augmented reality training. Participants performed a visuomotor walking task, where they must change their step length to hit visual targets while walking on a treadmill in an augmented reality environment. The study design was derived from Perez, Wise, Willingham, and Cohen (2007), Willingham, Wells, Farrell, and Stemwedel (2000), who have presented a method to identity training effects in motor learning tasks. Augmented reality training is expected to be intuitive to the user, therefore it was hypothesized that subjects are able to hit the visual targets at first try and that they show the ability to learn a sequenced walking task.

2. Materials and methods

Twenty participants (age 28.5 ± 7.2 years, 9M/11F) completed the training and all participants performed seven consecutive blocks of training to measure the performance and learning effects. This study was approved by the local Institutional Review Board. All methods conformed to the Declaration of Helsinki. All subjects gave written informed consent prior to participation.

2.1. Apparatus

The C-Mill (MotekForceLink, Amsterdam, The Netherlands) was used for the walking tasks. The C-Mill consists of an instrumented treadmill with an embedded force platform and a beamer that projects visual stepping targets (10 × 10 cm) on the walking surface (Fig. 1A) and therefore represents an augmented reality training environment. Position of foot placement was defined as the center of pressure (CoP) at the end of mid-stance, meaning that at that time it was underneath the (marked) 5th metatarsal (Winter, Patla, & Frank, 1990). The supplied CueFors 2.0 Software provides spatiotemporal data with respect to the presented visual targets.

2.2. Procedure

Within the training set-up, two groups of ten participants were formed based on a (randomized) imposed walking speed. Speed was set at 2.3 ± 0.2 km/h for the lower speed group and 3.3 ± 0.2 km/h for the higher speed group, to manipulate task difficulty.

We measured the change in performance across seven consecutive training blocks (performed on the same day), each block consisting of 100 stepping targets (and thus 100 steps) (Fig. 1B). Stepping targets were placed at short (80% of medium step length), medium (100%) or long (120%) stepping distances, in a random or sequenced order depending on the training block in the experiment. The medium step length was equal to 2/3 of the subject's leg length. Width between the stepping targets was set in correspondence to the step width of each subject. The first random block (*R1*) was used to familiarize the subject to the task. In this block, distance between stepping targets was presented in a random manner, with no recurring pattern in the distance between the stepping targets. The second random block (*R2*) provided a measure of final baseline performance and again, a random order was used in the distance between the stepping targets to evoke a mixture of short, medium and long steps. In the subsequent third, fourth and fifth training blocks (referred to by Fig. 1B as *S1*–*S3*), participants were presented with a repeating step length sequence. This