Neuroscience 337 (2016) 267–275

IMPACT OF ONLINE VISUAL FEEDBACK ON MOTOR ACQUISITION AND RETENTION WHEN LEARNING TO REACH IN A FORCE FIELD

C. S. BATCHO,[a,b] M. GAGNÉ,[a] L. J. BOUYER,[a,b] J. S. ROY[a,b] AND C. MERCIER[a,b*]

[a] *Centre interdisciplinaire de recherche en réadaptation et intégration sociale (CIRRIS), Quebec City, Quebec, Canada*

[b] *Department of Rehabilitation, Faculty of Medicine, Université Laval, Quebec City, Quebec, Canada*

Abstract—When subjects learn a novel motor task, several sources of feedback (proprioceptive, visual or auditory) contribute to the performance. Over the past few years, several studies have investigated the role of visual feedback in motor learning, yet evidence remains conflicting. The aim of this study was therefore to investigate the role of online visual feedback (VFb) on the acquisition and retention stages of motor learning associated with training in a reaching task. Thirty healthy subjects made ballistic reaching movements with their dominant arm toward two targets, on 2 consecutive days using a robotized exoskeleton (KINARM). They were randomly assigned to a group with (VFb) or without (NoVFb) VFb of index position during movement. On day 1, the task was performed before (baseline) and during the application of a velocity-dependent resistive force field (adaptation). To assess retention, participants repeated the task with the force field on day 2. Motor learning was characterized by: (1) the final endpoint error (movement accuracy) and (2) the initial angle (iANG) of deviation (motor planning). Even though both groups showed motor adaptation, the NoVFb-group exhibited slower learning and higher final endpoint error than the VFb-group. In some condition, subjects trained without visual feedback used more curved initial trajectories to anticipate for the perturbation. This observation suggests that learning to reach targets in a velocity-dependent resistive force field is possible even when feedback is limited. However, the absence of VFb leads to different strategies that were only apparent when reaching toward the most challenging target.

Key words: motor learning, reaching, force field adaptation, visual feedback.

INTRODUCTION

During motor rehabilitation, patients have to learn or relearn motor skills in order to perform better during activities of daily living. This learning process requires repeated training (Kantak and Winstein, 2012). Different sources of feedback (e.g. proprioceptive, visual, auditory) can be used during training to improve performance (Ernst and Banks, 2002; Safstrom and Edin, 2004; Franklin et al., 2007). The role of visual feedback in motor learning has been the subject of multiple studies, but available evidence is conflicting (DiZio and Lackner, 2000; Franklin et al., 2007; Arce et al., 2009; Cressman and Henriques, 2010; Sarlegna et al., 2010; Henriques and Cressman, 2012; Barkley et al., 2014; Schween et al., 2014; Yamamoto and Ohashi, 2014; Farshchiansadegh et al., 2015). Some studies (DiZio and Lackner, 2000; Lackner and DiZio, 2002; Franklin et al., 2007) have concluded that there is no benefit in providing visual feedback during motor learning, for example during a reaching task in a perturbed environment, while others (Ghez et al., 1995; Bernier et al., 2006; Sarlegna et al., 2010) have suggested that it may enhance motor performance. Ghez et al. (1995) and Sarlegna et al. (2010) examined the reaching performance of deafferented patients and found that vision can compensate for the permanent loss of proprioception to allow motor adaptation (Ghez et al., 1995; Sarlegna et al., 2010). Interestingly, congenitally blind individuals can rely on proprioceptive information to adapt their movement in the presence of perturbing forces (DiZio and Lackner, 2000), suggesting that motor adaptation can also occur without visual feedback. Such studies involved very specific populations with a longstanding sensory deprivation, and their findings are therefore difficult to generalize. Nevertheless, they suggest that visual and proprioceptive inputs represent different sources of feedback that may be tapped into for motor learning.

Many studies have investigated interactions between vision and proprioception during upper limb movements, including reaching and matching tasks (Flanagan and Rao, 1995; Sergio and Scott, 1998; Scheidt et al., 2005; Gosselin-Kessiby et al., 2008, 2009; Judkins and Scheidt, 2014). These studies have concluded that visual and proprioceptive feedback may be combined in fundamentally different ways during trajectory control and final position regulation of upper limb movements (Scheidt et al., 2005). Even though suppression of visual feedback may induce disruptions of adaptive responses (Scheidt et al., 2005), proprioceptive inputs appear to be sufficient

*Corresponding author. Address: Centre interdisciplinaire de recherche en réadaptation et en intégration sociale (CIRRIS), Université Laval, 525 boul. Hamel, Quebec, QC G1M 2S8, Canada. E-mail address: catherine.mercier@rea.ulaval.ca (C. Mercier).

URL: http://www.cirris.ulaval.ca/en/catherine-mercier (C. Mercier).

Abbreviations: fERR, final error; FFd1-Early, trials 2–11 during force field on day 1; FFd1-Late, last 10 trials during force field on day 1; FFd2-Early, trials 2–11 during force field on day 2; iANG, initial angle; KINARM, kinesiological instrument for normal and altered reaching movements; VFb, online visual feedback.

http://dx.doi.org/10.1016/j.neuroscience.2016.09.020
0306-4522/

to guide movement direction (Sergio and Scott, 1998; Scheidt et al., 2005; Gosselin-Kessiby et al., 2008, 2009). These findings have been corroborated by the performance of congenitally blind (Sergio and Scott, 1998; Gosselin-Kessiby et al., 2009) or blindfolded normally sighted subjects (Sergio and Scott, 1998; Gosselin-Kessiby et al., 2008) during a variety of upper limb tasks. However, these studies were mainly concerned with the effect of visual feedback on the linearity of movement path; it is therefore difficult to extrapolate these findings to the role that online visual feedback (VFb) might have during motor learning.

A few other studies have investigated the impact of VFb on motor learning during reaching in a perturbed condition (Arce et al., 2009; Schween et al., 2014; Yamamoto and Ohashi, 2014). Focusing on the motor acquisition phase, Schween et al. tested the impact of visual feedback provided either online or post-trial on motor learning processes and reported that VFb promotes implicit adaptation more than does post-trial feedback (Schween et al., 2014). Yamamoto et al., using an experimental design that allowed testing both acquisition and retention, suggested that both online and post-trial (provided after each block of 6 trials) visual feedback have similar effects on motor learning (Yamamoto and Ohashi, 2014). Finally, Arce et al., 2009 made very interesting observations regarding the influence of VFb on trajectories and adaptation strategies during reaching (Arce et al., 2009): although both visual conditions led to comparable terminal accuracy, in the presence of visual feedback, adapted hand trajectories in the force field were straight whereas they remained deviated in the direction of the force field in the absence of vision.

The differences in the design of these studies (Arce et al., 2009; Schween et al., 2014; Yamamoto and Ohashi, 2014), limit comparison. Further studies need to readdress the effect of VFb through a comparable protocol, in order to obtain clearer evidence on its role during motor learning. Therefore, the aim of the present study was to investigate the role of VFb on the acquisition and retention of motor learning during a reaching task in a force field environment. We compared the motor performance (reaching accuracy and adaptation strategy) in two groups of healthy subjects exposed to different types of visual feedback. In one group, visual feedback was provided throughout the movement with a visual cursor depicting index motion (VFb-group) while in the second group, the visual cursor was absent during index motion (i.e. no online visual feedback; NoVFb-group). More specifically, participants in the NoVFb-group were only aware of finger position before movement onset and were informed whether or not they actually reached the target.

EXPERIMENTAL PROCEDURES

Participants

Thirty healthy participants were randomly assigned to a group with (VFb-group, $n = 15$) or without (noVFb-group, $n = 15$) online visual feedback of index position during the reaching task. They had no prior experience with the experiment. All had normal or corrected-to-normal vision, and did not report any known neurological or musculoskeletal disorders that could affect task performance. Except for one subject in the NoVFb-group, all were right-handed according to the Edinburg handedness inventory (Oldfield, 1971).

This study was approved by the local ethics review board and all participants provided written informed consent prior to inclusion.

Protocol

Each participant came to the laboratory on two consecutive days. On day 1, they performed a reaching task before (Baseline) and during the application of a force field (Adaptation) that perturbed their movement. The force field, consisting in a velocity-dependent resistive force of -3 Nm·s/rad applied at the elbow, was unexpectedly turned on after the last trial of the Baseline. Subjects were aware that a perturbation would be applied, but the nature and the timing of the perturbation was unknown. No washout period was provided. On day 2, the task was only performed in the presence of the force field, to assess Retention.

Fig. 1 presents a schematic view of the experimental set-up and task description. The reaching task was performed using the KINARM (BKIN Technologies, Canada), a robotized exoskeleton that allows combined movements of the shoulder (horizontal abduction–adduction) and elbow (flexion–extension) joints in order to move hand toward targets in the horizontal plane (Scott, 1999). In the present study, participants performed blocks of ballistic reaching movements with their dominant arm toward two targets (Far and Near) in a pseudo-random sequence. Targets projected in the horizontal plane were located 10 cm away from the central starting position, one at 120° (Far) and the other at 300° (Near). For the left-handed subject, the task was performed with the left arm: the targets locations were mirror-transformed to ensure that movements were biomechanically equivalent to the other participants. Two targets (Far and Near) were chosen for training to engage cognitive processing leading to a strong motor memory representation (Kantak and Winstein, 2012), and force field exposure always started with two trials toward the Far target. One hundred trials (50/target; test duration 8 min) were performed in each of Baseline, Acquisition and Retention tests.

Experiments were carried out in a quiet and dark room, so that subjects had no direct vision of theirs arms. In addition, subjects' forearms were hidden with an opaque shutter attached between the projection surface and the subjects' trunk.

A white dot (1 cm diameter) was calibrated to allow visual feedback of index location when appropriate. The VFb allowed online adjustment of movement trajectory while reaching to the target, i.e. the index location was displayed continuously. The NoVFb-group was provided with the index location only at the starting position before each trial. Targets were flashed for a maximum of 700 ms on the horizontal screen, requiring that