ARTICLE IN PRESS

Human Movement Science xxx (2013) xxx–xxx

Contents lists available at ScienceDirect

Human Movement Science

journal homepage: www.elsevier.com/locate/humov

Retrieval practice in motor learning

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ARTICLE INFO

Article history:
Available online xxxx

PsycINFO classification:
2330
2340
2343

Keywords:
Retrieval practice
Testing
Encoding
Consolidation
Effector transfer
Motor learning

ABSTRACT

In this study we sought to determine whether testing promotes the generalization of motor skills during the process of encoding and/or consolidation. We used a dynamic arm movement task that required participants to reproduce a spatial-temporal pattern of elbow extensions and flexions with their dominant right arm. Generalization of motor learning was tested by the ability to transfer the original pattern (extrinsic transformation) or the mirrored pattern (intrinsic transformation) to the unpractised left arm. To investigate the testing effects during both encoding and consolidation processing, participants were administered an initial testing session during early practice before being evaluated on a post-practice testing session administered either 10 min (Testing-Encoding group) or 24 hr apart (Testing-Consolidation group), respectively. Control groups were required to perform a post-practice testing session administered after either a 10-min (Control-Encoding group) or 24-hr delay (Control-Consolidation group). The findings revealed that testing produced rapid, within-practice skill improvements, yielding better effector transfer at the 10-min testing for the Testing-Encoding group on both extrinsic and intrinsic transformation tests when compared with the Control-Encoding group. Furthermore, we found better performance for the Testing-Consolidation group at the 24-hr testing for extrinsic and intrinsic transformations of the movement pattern when compared with the Control-Consolidation group. However, our results did not indicate any significant testing advantage on the latent, between-session development of the motor skill representation (i.e., from the 10-min to the 24-hr testing). The testing benefits

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http://dx.doi.org/10.1016/j.humov.2012.10.002

Please cite this article in press as: Boutin, A., et al. Retrieval practice in motor learning. *Human Movement Science* (2013), http://dx.doi.org/10.1016/j.humov.2012.10.002

expressed at the 10-min testing were stabilised but did not extend during the period of consolidation. This indicates that testing contributes to the generalisation of motor skills during encoding but not consolidation.

1. Introduction

Behavioral and neurophysiological studies suggest that motor skill learning is characterized by distinct and successive phases. The acquisition of a new motor skill relies on a fast, within-practice phase of performance improvement that is followed by a slow learning phase consisting of delayed, time-dependent performance improvements occurring off-line between practice sessions (e.g., Karni & Bertini, 1997; Karni et al., 1995; Korman, Raz, Flash, & Karni, 2003; Robertson, Pascual-Leone, & Press, 2004; see also Krakauer & Shadmehr, 2006; Stickgold & Walker, 2007, for reviews). The off-line learning process refers to a spontaneous improvement in performance without additional practice (Walker, 2005), intent or awareness (Stickgold & Walker, 2007), where the new and initially labile task representation is strengthened and becomes integrated into the network of pre-existing and long-lasting motor skill representations (>24 hours; see Krakauer & Shadmehr, 2006, for a review). These post-practice processes are essential to the formation and long-term storage of motor representations, and have been grouped under the term "consolidation" (e.g., Krakauer & Shadmehr, 2006; McGaugh, 2000; Robertson, Pascual-Leone, & Miall, 2004; Stickgold & Walker, 2007).

Skill development during consolidation is characterised by either a quantitative increase in performance or a qualitative representational change (see Robertson, 2009). For instance, qualitative changes might be expressed by a shift in the strategy used to solve a problem (e.g., Wagner, Gais, Haider, Verleger, & Born, 2004) or by a shift in reliance from one coding system to another (e.g., Boutin et al., 2012a; Kovacs, Muehlbauer, & Shea, 2009). In accordance with this notion, it has recently been proposed that latent formation of motor representations is supported by the development of two distinct skill components that operate together to mediate off-line learning (Boutin et al., 2012a). The skill components that develop off-line can be distinguished as either intrinsic or extrinsic coding systems (e.g., Criscimagna-Hemminger, Donchin, Gazzaniga, & Shadmehr, 2003; Hikosaka et al., 1999; Lange, Godde, & Braun, 2004). Each coding system contributes to movement production and can produce specific learning and transfer capabilities (e.g., Boutin et al., 2012a; Boutin, Fries, Panzer, Shea, & Blandin, 2010; Panzer, Krueger, Muehlbauer, Kovacs, & Shea, 2009).

While the visually acquired information on movement and target positions is initially encoded in an eye-centred, extrinsic world-based reference frame, the muscular activation patterns are then encoded in an intrinsic, body-centred reference frame (e.g., Colby & Goldberg, 1999; Soechting & Flanders, 1989). The intrinsic code is represented as an internal model of joint representations (Criscimagna-Hemminger et al., 2003), musculoskeletal forces, and dynamics (Krakauer, Ghilardi, & Ghez, 1999) that takes the relative orientation of body segments into account (Lange et al., 2004; Soechting & Flanders, 1989). The intrinsic coding system is thought to result in a representation of the motor skill that is effector-dependent and lacks transfer capability. Conversely, the extrinsic code reflects the Cartesian coordinates of the task space with respect to the visual display and results in an effector-independent representation with effector transfer capability (Hikosaka et al., 1999).

Recently, Boutin and colleagues (2012a) investigated the effects of practice on effector transfer and the associated skill representational changes that occur during the within-practice and between-practice phases. Interestingly, they found that practice induces rapid and non-transferable (effector-dependent) motor skill improvements, with the extrinsic component of the skill developing early and remaining the dominant coding system during practice. Conversely, their findings revealed latent and practice-dependent reorganisations of the motor skill during the off-line period: limited practice induced an off-line development of the extrinsic component, whereas prolonged practice subserved an off-line development of the intrinsic component. Practice has been proposed to trigger rapid and latent reorganisations of the motor skill representation, thus yielding distinct immediate and long-term transfer capabilities.

Please cite this article in press as: Boutin, A., et al. Retrieval practice in motor learning. *Human Movement Science* (2013), http://dx.doi.org/10.1016/j.humov.2012.10.002