Cognition 133 (2014) 1–9

Contents lists available at ScienceDirect

Cognition

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

Conscious awareness of action potentiates sensorimotor learning

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ARTICLE INFO

Article history:
Received 7 October 2013
Revised 20 May 2014
Accepted 22 May 2014

Keywords:
Action awareness
Unconscious processing
Sensorimotor learning
Chunking
Skilled actions

ABSTRACT

Many everyday skills are unconsciously learned through repetitions of the same behaviour by binding independent motor acts into unified sets of actions. However, our ability to be consciously aware of producing newly and highly trained motor skills raises the question of the role played by conscious awareness of action upon skill acquisition. In this study we strengthened conscious awareness of self-produced sequential finger movements by way of asking participants to judge their performance in terms of maximal fluency after each trial. Control conditions in which participants did not make any judgment or performance-unrelated judgments were also included. Findings indicate that conscious awareness of action, enhanced via subjective appraisal of motor efficiency, potentiates sensorimotor learning and skilful motor production in optimising the processing and sequencing of action units, as compared to the control groups. The current work lends support to the claim that the learning and skilful expression of sensorimotor behaviours might be grounded upon our ability to be consciously aware of our own motor capability and efficiency.

1. Introduction

Many of our everyday skills are motor acts that we perform repeatedly and almost without any conscious control (Graybiel, 2008). Even when performed intentionally, the motor-skill details and their changes over the course of learning generally remain outside the scope of awareness (e.g., Fourneret & Jeannerod, 1998; Willingham, 2001). Nonetheless, we have the conscious experience of generating our own actions (Berti & Pia, 2006) and may further become aware of movement components we are normally not aware of, which can result in improved or impaired motor performance (see Heuer & Sülzenbrück, 2012, for a review). Such a complex relationship between conscious awareness of action and motor performance has motivated us to address the role of conscious awareness of action for motor-skill learning.

The learning of sequential finger movements – related to everyday skills such as writing, typing, or playing musical instruments – is particularly well-suited to the aim of the present study as it allows the investigation of different kinds of conscious monitoring of motor skills. For instance, while playing a highly trained sonata on a piano, one may be consciously aware of the resulting sounds and the general production of hand movements. However, occasionally one might also be aware of the spatial goals of movements, that is, the proper keys to be hit. In very rare cases one might even become aware of the fast and efficient adjustments of fine finger movements (see Porter & Lemon, 1993). Overall, the production of highly skilled finger movements relies on the conflation of

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http://dx.doi.org/10.1016/j.cognition.2014.05.012
0010-0277/

distinct, but interacting, conscious and unconscious control processes. The understanding of this crosstalk between conscious and unconscious monitoring of sensorimotor behaviours during skill learning is an important issue that needs to be addressed.

Several lines of evidence suggest that skilled sequential behaviours are formed through action–rehearsal and gradual structuring of independent units of actions into sequentially ordered subsets, without conscious awareness playing an essential role (see Graybiel, 2008; Sakai, Hikosaka, & Nakamura, 2004, for reviews). Behind every skilled sequential action, for example in response to repeated strings of environmental information, lies a learning-related process known as *chunking* (Miller, 1956). The chunking of independent motor acts during skill learning is manifested by our ability to sequence units of actions in specific order and rhythm to achieve coherent and skilled performance when the same and regular sensory stimulation is repeated over time (Boutin, Fries, Panzer, Shea, & Blandin, 2010). The resultant segmented representation of the entire set of actions into unified subsets through chunking is considered the hallmark of learned sensorimotor behaviours (Graybiel, 2008).

In the present study, we used a sequential key-press task to determine whether subjective appraisal of the motor act affects motor performance and sequence learning. To that end, we instructed participants to judge their own performance after each completion of a finger-movement sequence (awareness group). In this condition, learners were required to verbally report after each trial whether they felt that they had performed the task in the most rapid and fluent fashion possible for them, which relates to individual subjective standards of maximal performance. Motor performance in the awareness group was compared to a yoked-control group in which participants also made a judgment on each practice trial, but without that judgment being related to their own performance (irrelevant-judgment control). Rather participants were required to report whether the tone, which served as a start signal for a specific trial, differed from the original one. Specifically, each participant in the irrelevant-judgment control condition was paired to one participant in the awareness group, such that being aware of the occurrence of a different starting tone corresponds to subjective maximal performance for his/her respective awareness learner. Furthermore, to rule out any potential interference of the irrelevant judgments with motor learning, a no-judgment control condition in which participants did not make any judgment was included as well.

As studied in the present experiment, subjective appraisal of motor efficiency leads to a specific type of action awareness, referred to as subjective awareness of action (SAA). It has to be distinguished from other types, in particular from those types that can disrupt relatively automatic processes that normally control efficient execution of skilled movements (see Wulf & Prinz, 2001, for a review). In our study, SAA relates to an off-line individual judgment of one's own performance relative to a subjective standard (i.e., self-efficacy; Bandura, 1997). In a classic theory of maximising motor proficiency, such subjective overall evaluation has been ascribed a critical role for the selection of the fastest ways to perform a certain task (Crossman, 1959). Consistent with this perspective, SAA should promote learning at a cognitive level in driving the optimisation of the organisation of action units. Thus, SAA should facilitate the processing of transitions between chunks, which are thought of as being cognitively mediated, but not the processing of transitions within chunks that are assumed to be carried out automatically without cognitive involvement (e.g., Rushworth, Walton, Kennerley, & Bannerman, 2004; Sakai et al., 2004). In contrast, the detection of a variant tone between trials in the irrelevant-judgment condition should not induce any particular performance change. Therefore we expected similar performance in both the irrelevant- and no-judgment control conditions.

As posited by Baars (1988) in his *global workspace* framework and *conscious access hypothesis* (Baars, 2002), consciousness is associated with the availability of multiple sensory inputs in distributed neural networks and with the mobilisation of specialised brain functions such as problem solving, decision-making, and action planning. Such high-level cognitive processes can solve conflicts between motor plans. In spite of simultaneously activated response tendencies, a single (integrated) motor plan has to be selected at a time to yield a single and appropriate motor action (Morsella, 2005). Consciousness is considered as facilitating the widespread access and interaction between distinct brain functions (Morsella, 2005), yielding subjective experience by providing global availability of information throughout the distributed network (Dehaene & Naccache, 2001). In our current task, SAA may also serve a metacognitive function in terms of the selection and planning of progressively more skilled sequence production: Of two action plans directed to the same goal, one would select the subjectively higher evaluated plan which is associated with better performance and smoother motor responses. Therefore, we predict that SAA and high-level top-down (meta-) cognitive processing might go along with enhanced task performance in the awareness group, as compared to the irrelevant- and no-judgment control groups, but not necessarily with higher explicit (conscious) knowledge of the hierarchical motor response structure. Indeed, the aforementioned brain-function interactive process can remain beyond the scope of awareness of the details (Morsella, 2005), and SAA does not imply conscious knowledge of the target stimuli *per se*.

2. Method

2.1. Participants

Forty-five undergraduate students (20.1 ± 2.5 years, mean age ± standard deviation, 18 females) volunteered to participate in this study. Participants were right-hand dominant as determined by the Edinburgh Handedness Inventory (Oldfield, 1971), had no prior experience with the experimental task, and were not aware of the specific purpose of the study. Informed consent was obtained before the experiment.