Neurobiology of Learning and Memory 140 (2017) 27–32

Contents lists available at ScienceDirect

Neurobiology of Learning and Memory

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

Short communication

Background matters: Minor vibratory stimulation during motor skill acquisition selectively reduces off-line memory consolidation

Maria Korman [a,*], Zohar Herling [b], Ishay Levy [a], Nebal Egbarieh [a], Batya Engel-Yeger [a], Avi Karni [b]

[a] Department of Occupational Therapy, Faculty of Social Welfare & Health Sciences, University of Haifa, Israel
[b] Department of Human Biology, Faculty of Natural Sciences, University of Haifa, Israel

ARTICLE INFO

Article history:
Received 29 July 2016
Revised 8 January 2017
Accepted 7 February 2017
Available online 9 February 2017

Keywords:
Online and offline learning
Procedural memory
Consolidation
Sensory stimulation
Whole-body vibration
Sensory interference
Vibratory noise

ABSTRACT

Although a ubiquitous situation, it is not clear how effective is a learning experience when task-irrelevant, sensory noise occurs in the background. Here, young adults were trained on the finger opposition sequence task, in a well-established training and testing protocol affording measures for online as well as off-line learning. During the training session, one group experienced a minor background vibratory stimulation to the trunk by the means of vibrating cushion, while the second group experienced recorded sound vibrations. A control group was trained with no extra sensory stimulation. Sensory stimulation during training had no effect on the online within-session gains, but dampened the expression of the off-line, consolidation phase, gains in the two sensory stimulation groups. These results suggest that background sensory stimulation can selectively modify off-line, procedural memory consolidation processes, despite well-preserved on-line learning. Classical studies have shown that neural plasticity in sensory systems is modulated by motor input. The current results extend this notion and suggest that some types of task-irrelevant sensory stimulation, concurrent with motor training, may constitute a 'gating' factor - modulating the triggering of long-term procedural memory consolidation processes. Thus, vibratory stimulation may be considered as a behavioral counterpart of pharmacological interventions that do not interfere with short term neural plasticity but block long-term plasticity.

1. Introduction

Skillful performance of motor sequences can be learned explicitly, e.g., in finger-opposition or finger-tapping paradigms (Doyon et al., 2009; Friedman & Korman, 2012; Korman, Raz, Flash, & Karni, 2003) or implicitly, e.g., in serial reaction time paradigms (Destrebecqz & Peigneux, 2005; Janacsek & Nemeth, 2012), depending on the intention or awareness during acquisition (Keele, Ivry, Mayr, Hazeltine, & Heuer, 2003; Robertson, 2007). Both types of sequence learning depend on the amount of practice (Karni, 1996), however, although task repetition is a necessary prerequisite of improving performance during the training session, it is neither optimal nor sufficient for stabilization and enhancement of skill representation after the termination of training. Motor skill (procedural, "how to" knowledge) evolves through distinctive phases (Luft & Buitrago, 2005), with performance gains expressed during the learning experience (online learning) but also after the termination of training, as delayed, offline, gains (Karni et al., 1998; Korman et al., 2003); the latter presumably reflect procedural memory consolidation (PMC) processes (Karni & Korman, 2011). Factors such as the amount of practice, task relevancy and reward expectation, but also subsequent experience and post-training sleep, may selectively affect – block or accelerate – PMC (Albouy et al., 2016; Born & Wilhelm, 2012; Diekelmann & Born, 2010; Fischer & Born, 2009; Friedman & Korman, 2016; Hauptmann & Karni, 2002; Korman, Flash, & Karni, 2005; Korman et al., 2003, 2007). Thus, whether PMC is successfully completed is under strict control ("gating") (Adi-Japha & Karni, 2016; Karni & Korman, 2011) both during, and in the hours following, practice.

It has been proposed that attention influences within-session, "online", learning by 'highlighting' and selecting the neural circuits that should undergo modification (Fritz, Elhilali, & Shamma, 2007). Sensory afferent information can influence primary motor cortex plasticity by favoring or inhibiting the recruitment of specific muscle representations (Popa et al., 2013). Increasing visual attention demands were shown to decrease motor cortex plasticity suggesting that reduced attention to the task can suppress plasticity (Kamke et al., 2012). Animal studies suggest that attention is important not only for enhancement of learning-related plasticity of task-relevant features, but also for inhibition of plasticity for

* Corresponding author.
E-mail address: korman.maria@gmail.com (M. Korman).

http://dx.doi.org/10.1016/j.nlm.2017.02.002
1074-7427/

task-irrelevant features (Polley, Steinberg, & Merzenich, 2006; Roelfsema, van Ooyen, & Watanabe, 2010). Lavie (2005, 2010) proposed that the greater the attentional investment in a primary task, the fewer resources are available for processing irrelevant stimuli; the cost of reduced attention in motor tasks is reflected in reductions of reaction times, accuracy and consistency of performance (Kindlon, 1998). Distraction of attention has been considered as a factor in not only the induction of immediate performance reduction (thus less effective within-session learning) but also in the presumed sleep-dependent consolidation of the explicit aspects or components of newly learned tasks (Diekelmann & Born, 2010). Nevertheless, multisensory integration effects (Hecht, Reiner, & Karni, 2008) and the classical paradigms showing that motor activity significantly enhances sensory plasticity (Held & Hein, 1958; Pettorossi & Schieppati, 2014) suggest that factors other than online load may be critical; for example, sensory input acquired during active motor exploration was more effective in driving visual plasticity than sensory input without concurrent motor activity (Held & Hein, 1958).

There are apparently contradictory observations and theoretical claims (Bazett-Jones, Finch, & Dugan, 2008; Issurin, 2005; Rauch, 2009) about the impact of task-irrelevant sensory stimulation on attention, skills performance and memory. Incidental sensory processing concurrent with a memory task may divert attention from the intentional memory items (Oberauer, Farrell, Jarrold, Pasiecznik, & Greaves, 2012), preventing their maintenance or further consolidation into long-term memory (Barrouillet, Bernardin, & Camos, 2004). On the other hand, vibro-sensory (Fuermaier et al., 2014) and auditory white noise (Baijot et al., 2016) stimulation have been proposed as means to enhance attention and benefit learning processes (Fuermaier et al., 2014; Ljungberg & Neely, 2007; Sandover & Champion, 1984; Sherwood & Griffin, 1992). Whole body vibration is even suggested as an adjunct in enhancing motor training (Cardinale & Bosco, 2003) and rehabilitation (Madou & Cronin, 2008) (but see (Lau et al., 2011)), presumably as an alerting intervention for improving vigilance (Dolny & Reyes, 2008).

Vibratory stimulation is inherently multi-modal and includes both auditory and vibrotactile inputs, tuned to the same kind of physical property - mechanical pressure in the form of oscillations: the very same vibratory stimulus is experienced simultaneously by the peripheral receptor organs of both sensory modalities in the cochlea and the skin (Soto-Faraco & Deco, 2009). In the audio-vibrotactile domain there are demonstrations of tactile influences on the perception of sound (Bresciani & Ernst, 2007; Caclin, Soto-Faraco, Kingstone, & Spence, 2002; Murray et al., 2005), as well as of auditory influences in the perception of touch (Bresciani et al., 2005; Soto-Faraco, Spence, & Kingstone, 2004).

However, previously, there was no empirical evidence to suggest that vibration, auditory or tactile-auditory, may specifically affect PMC processes. Here, using a training protocol that effectively induces motor sequence memory consolidation, we tested parameters of motor performance within (online) and between (offline) sessions, and their sensitivity to two types of task-irrelevant, low-intensity vibratory stimulation, in the form of either multimodal vibrotactile-auditory or unimodal vibratory auditory noise. We report that minor background sensory noise, afforded only during training, had no immediate deleterious effects on "online" learning but selectively reduced the overnight expression of delayed "offline" gains in the performance of a novel motor skill.

2. Methods

Forty eight young (20–35yrs, 24.3 + 4.31) healthy participants were trained on the finger opposition sequence learning task, using a well-established training protocol that effectively induces PMC (Korman et al., 2003), either with incidental vibro-tactile stimulation to the trunk, or with recorded vibratory auditory noise, or without stimulation (Fig. 1). Enrollment of potential participants was through advertisements at the University of Haifa, for a study "on motor learning and memory" on a voluntary basis. Informed consent was obtained before the experiment and the study was approved by the Ethics Committee of University of Haifa. Participants were right-handed, as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971) and had no medical conditions, such as learning and ADHD disabilities, neurological, psychiatric and medical disorders, skeletal or muscle disease, serious sensory or motor impairments, or chronic medication use, that could impair fine motor performance. Only participants with scores above the cut-off for sleep quality were included (PSQI questionnaire (Buysse, Reynolds, Monk, Berman, & Kupfer, 1989). All participants exhibited typical sensory sensitivity scores, according to Adolescent/Adult Sensory Profile (AASP) questionnaire (Dunn, 2001). Musicians and professional typists were excluded. Subjects were asked not to ingest caffeine and alcohol during the days of the experiment.

The participants were randomly assigned for a single experimental condition: 16 subjects were trained with vibro-tactile stimulation (ViSS – vibro-tactile sensory stimulation group); 16 subjects were trained with vibro-auditory sensory interference (AuSS auditory sensory stimulation group); and 16 subjects were trained without background sensory stimulation (NoSS group, control). Participants were invited for the experiment in two successive days, during morning to early afternoon hours (08:30–13:00). The instructions, testing and training procedure on the assigned 5-element sequence were according to a modified structured protocol by Korman et al. (2003) and requested to oppose the fingers of the left (non-dominant) hand to the thumb in a given order: 4,1,3,2,4 (Fig. 1). In the first day, following the explanation of the task and three warm-up trials, each participant performed a pre-training performance test (PT1), a training, and an immediate post-training performance test (PT2). Participants were instructed not to practice the task between the meetings. In the second day,

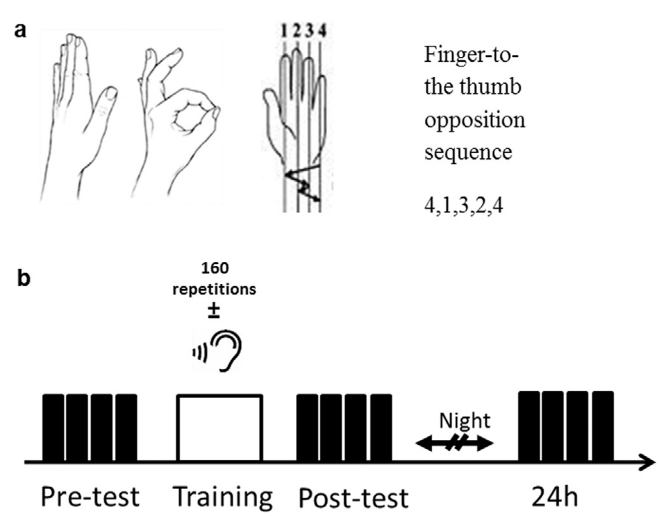

Fig. 1. Study task and design. (a) The finger-to-thumb opposition task. (b) Participants were trained (white box - 160 cued repetitions of the sequence) in a single session at noon. Performance was tested in 3 time-points: pre-test, post-test, and 24 h post-training (black boxes – 30 s. test blocks). The ViSI group experienced vibratory stimulation on their trunk during training blocks, concurrent with the motor sequence training. Stimulation levels were rated as not or only minimally uncomfortable.