RESEARCH NOTE

Otmar Bock · Monika Thomas · Valentina Grigorova

The effect of rest breaks on human sensorimotor adaptation

Abstract We have studied the effect of rest breaks on sensorimotor adaptation to rotated visual feedback in a pointing task. Adaptive improvement was significantly poorer after 1-s breaks than after 5–40-s breaks, with no significant difference among the latter break durations. The benefit of >1-s breaks emerged soon after the onset of adaptation, and then remained steady throughout the adaptation, retention (next day), and persistence (no feedback) phases. This pattern of findings indicates that break-induced facilitation is not a result of strategic adjustments, motivation, or recovery from fatigue, but rather to consolidation of previously acquired sensorimotor recalibration rules.

Keywords Motor learning · Massed practice · Distributed practice · Adaptation · Sensorimotor integration · Humans

Introduction

When humans subjects are exposed to visual (Stratton 1897; Kohler 1955) or mechanical (Ghez et al. 1994; Shadmehr and Mussa-Ivaldi 1994) distortions their sensorimotor performance is first substantially degraded but adaptive recovery is observed during extended practice. It is well established that the final magnitude of this recovery is higher when practice takes longer, which indicates that adaptation is a gradual process. It is less well known, however, that adaptation also depends on the availability of rest breaks. Thus the final level of

O. Bock (✉) · M. Thomas
Institute of Physiology and Anatomy,
German Sport University, 50927 Köln, Germany
E-mail: bock@dshs-koeln.de
Tel.: +49-221-49823700
Fax: +49-221-49826790

V. Grigorova
Institute of Physiology,
Bulgarian Academy of Sciences, Sofia, Bulgaria

adaptation to laterally displaced vision was more pronounced when training was interrupted by rest breaks of 2 s (Choe and Welch 1974), 30 s (Taub and Goldberg 1973), or 120 s (Dewar 1970), rather than without such breaks. In other work breaks of 10 s versus 50 s had no differential effect on final adaptation magnitude (van Laer 1968). It would therefore appear that adaptation does benefit from rest breaks of 2 s or longer, and that this benefit may not necessarily depend on break length.

Given that the benefit of rest breaks was documented some 30 years ago, it seems surprising that it is often neglected in more recent adaptation literature. Many studies do not quantify break duration, do not specify whether it was rigidly controlled or left up to the subjects, or do not even state whether breaks were provided at all. This makes break duration a potentially confounding variable in studies which compare the magnitude of adaptation in different subject groups (e.g. different ages or treatments)—a less proficient group could mask a deficit by choosing longer breaks or one of two equally proficient groups could mimic a deficit by selecting shorter breaks.

One purpose of this study was to provide a more recent account of break-related benefits and to establish their validity for other visual distortions besides the lateral shifts investigated previously. A second purpose was to better understand the underlying mechanisms—we wanted to determine *at which time* during adaptation the benefits emerge (previous work focused on the *final* adaptation level), to quantify within a *single* experimental paradigm how the benefits depend on break duration, and to scrutinize whether the benefits are only temporary, and dissipate soon after testing, or, instead, are relatively persistent.

Methods

Subjects pointed with their right index finger at mirror-viewed targets (inset in Fig. 1), which appeared in a horizontal plane 12 cm from a starting dot, in one of
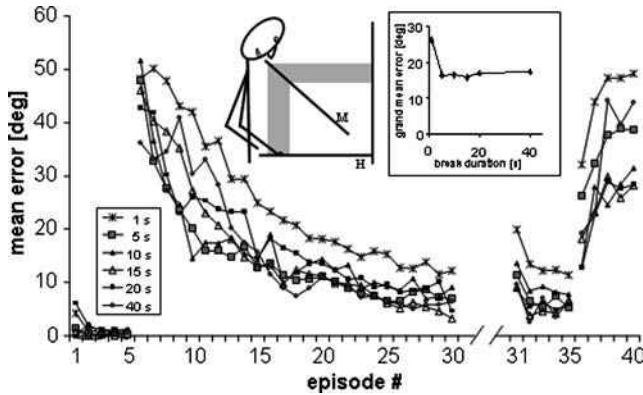
Fig. 1 Pointing errors before, during, and after adaptation to visual rotation. Different symbols represent subject groups with different rest break durations, and each symbol is the across-subject mean of the median error in a given episode. The *left inset* is a schematic diagram of our arrangement, where *M* is mirror and *H* the horizontal surface. The *right inset* is the grand mean error across all post-baseline episodes of the individual groups—note the distinct reduction of error when break duration exceeded 1 s, with no further reduction for longer breaks

eight possible directions. Each target was presented for 750 ms and was then replaced by the starting dot, which stayed on until the finger returned to the center and remained there for 750 ms; the next target was then selected in random order, etc. The mirror prevented subjects from seeing their hand, but fingertip position was registered by the Fastrak motion analysis system (resolution 120 Hz/1 mm) and displayed to them as a cursor. Subjects were instructed to point with the cursor at each target and back quickly and accurately.

The experiment was subdivided into episodes of 24 responses, or approximately 35 s, separated by rest breaks. The cursor provided veridical feedback about momentary finger position during the first five episodes (baseline phase). During the next 25 episodes feedback was distorted by a 60° clockwise rotation about the starting dot, and subjects were told that "the task will now become more difficult" (adaptation phase). A period of 24–36 h later, subjects returned to the laboratory and participated in five more episodes with 60° rotated feedback (retention phase), followed by five episodes without visual feedback (persistence phase).

The duration of rest breaks between episodes was computer-controlled. Subjects were subdivided into six groups, which were tested with breaks 1, 5, 10, 15, 20, or 40 s long. A no-break group was not included, because, in our experience, this causes substantial muscle fatigue and concentration loss. We initially assigned five subjects to each group, however, preliminary analyses indicates the only the 1-s group differed from the others, and we did not wish a significant effect of group to rely on merely five subjects. We therefore added another five subjects to the 1-s group, thus yielding a total sample size of 35. All subjects were right-handed, healthy, university students, participating to fulfil a course assignment. They were between 19 years and 31 years of age,

19 were male and 16 female, and none had prior experience of sensorimotor research. All signed an informed consent statement before participating in our study, which was pre-approved by the local Ethics Committee.

Results

We quantified pointing errors as the angular difference between required and actual response direction at the time of peak response velocity, and determined the median value of this error for each subject and episode. Figure 1 illustrates that these errors were small during the baseline phase, increased sharply at the onset of the adaptation phase and then gradually decreased again, remained low during the next-day retention phase, and gradually increased in the subsequent persistence phase without visual feedback. Most importantly from Fig. 1, errors in all but the baseline phase were consistently larger in the 1-s group than in the other groups. The only exception is the *first* episode of the adaptation phase, which occurred *before* the first break of the adaptation phase, and therefore naturally yielded no consistent group dependence. Our observations were confirmed by analysis of variance of post-baseline data, using the between-factor Group and the within-factor Episode. Significant effects were yielded for Episode ($F = 41.41$; $P < 0.001$) and Group ($F = 3.31$, $P < 0.05$), but not for their interaction ($F = 0.86$, $P > 0.05$). LSD tests confirmed that the 1-s group was significantly different from all other groups ($P < 0.01$ for 5, 10, and 15-s groups, $P < 0.05$ for 20 and 40-s groups), whereas the other groups did not differ among themselves (all $P > 0.05$). For those other groups there was not even a non-significant trend for post-baseline error to consistently change with break duration, as illustrated by the right inset of Fig. 1.

The benefit of rest breaks > 1 s on adaptive recalibration was calculated as:

$$B[\%] = \frac{p_1 - p_x}{p_1 - b} \times 100 \qquad (1)$$

where p_1 and p_x represent the mean error in the first persistence episode of the 1-s group and of the other groups, respectively, and b is the mean error of all groups in the last baseline episode. We thus obtained:

$$B[\%] = \frac{32.04 - 17.85}{32.04 - 0.38} \times 100 = 44.8 \qquad (2)$$

i.e. the recalibration error was reduced by nearly 50% with longer rest breaks compared with rest breaks of 1 s duration.

Discussion

Our data confirm that rest breaks have a beneficial effect on adaptation, and extend previous findings to visual

distortions other than lateral shifts. As in previous work, the benefit amounted to nearly 50% (Taub and Goldberg 1973; Choe and Welch 1974), and remained constant across a range of break durations (van Laer 1968). Besides yielding these confirmatory results, however, our present data also offer two new insights.

It is widely accepted (Redding 1996; McNay and Willingham 1998) that adaptive improvements are based on two types of phenomenon—a change of sensory-to-motor transformation rules, called *recalibration*, and response corrections based on anticipation, cognitive work-around, or sensory feedback, jointly called *strategic adjustments*. It is thought that retention and persistence tests are selectively sensitive to recalibration, because strategic adjustments dissipate within several hours of testing, and in the absence of error-correcting feedback. Retention tests are also thought to separate out the temporary effects of motivation and fatigue on subjects' performance (Schmidt 1971). Because in our study the benefit of rest breaks continued unabated throughout the retention and persistence phase (i.e. no significant interaction term), it seems that rest breaks mainly facilitate recalibration whereas their influence on strategic adjustments, motivation, and fatigue is limited.

We evaluated the effect of rest breaks not only on the final level of adaptation, but also on its time-course. We found that break-induced facilitation emerged early during the adaptation phase and remained stable thereafter, with no reliable sign of further deterioration or compensation (i.e. no significant interaction term). To interpret this finding, we suggest that most newly acquired knowledge is particularly large at the onset of the adaptation phase and a 1-s break is not enough to consolidate it into long-term memory. Less knowledge is acquired later during adaptation and a 1 s break is then sufficient for consolidation, but subjects cannot make up for a deficit that developed earlier on.

It is noteworthy that similar differences between "massed" and "distributed" practice were observed in motor learning paradigms other than adaptation (Lee and Genovese 1988), as well as in verbal learning paradigms (Ebbinghaus 1885; Glenberg 1979). Furthermore, animal research suggests that this difference may be related to differential modulation of protein synthesis-dependent molecular processes which affect the expression of synaptic connectivity (Genoux et al. 2002; Scharf et al. 2002). The proposed interplay between acquisition and consolidation may therefore represent a general principle of neural plasticity.

References

Choe C, Welch R (1974) Variables affecting the intermanual transfer and decay of prism adaptation. J Exp Psychol 102:1076–1084

Dewar R (1970) Adaptation to displaced vision—the influence of distribution of practice on retention. Percept Psychophys 8:33–34

Ebbinghaus H (1885) Über das Gedächtnis: Untersuchungen zur experimentellen Psychologie. Duncker & Humblot, Leipzig

Genoux D, Haditsch U, Knobloch M, Michalon A, Storm D, Mansuy I (2002) Protein phosphatase 1 is a molecular constraint on learning and memory. Nature 418:970–975

Ghez C, Krakauer J, Sainburg R, Ghilardi M-F (1994) Spatial representations and internal models of limb dynamics in motor learning. In: Gazzaniga M (ed) The cognitive neurosciences. MIT, Cambridge, pp 501–513

Glenberg A (1979) Component-levels theory of the effects of spacing of repetitions on recall and recognition. Mem Cognit 7:95–112

Kohler I (1955) Experiments with prolonged optical distortions. Acta Psychol 11:176–178

van Laer E (1968) Transfer effects in adaptation to prismatic displacement. Psychon Sci 13:85–86

Lee T, Genovese E (1988) Distribution of practice in motor skill acquisition: learning and performance effects reconsidered. R Q Exerc Sport 59:277–287

McNay EC, Willingham DB (1998) Deficit in learning of a motor skill requiring strategy, but not of perceptualmotor recalibration, with aging. Learn Mem 4:411–420

Redding G (1996) Adaptive spatial alignment and strategic perceptual-motor control. J Exp Psychol Hum Percept Perform 22:379–394

Scharf M, Woo N, Lattal K, Young J, Nguyen P, Abel T (2002) Protein synthesis is required for the enhancement of long-term potentiation and long-term memory by spaced training. J Neurophysiol 87:2770–2777

Schmidt R (1971) Proprioception and the timing of motor responses. Psychol Bull 76:383–393

Shadmehr R, Mussa-Ivaldi F (1994) Adaptive representation of dynamics during learning of a motor task. J Neurosci 14:3208–3224

Stratton GM (1897) Vision without inversion of the retinal image. Psychol Rev 4:341–481

Taub E, Goldberg I (1973) Prism adaptation: control of intermanual transfer by distribution of practice. Science 180:755–757