Acta Psychologica 170 (2016) 58–65

Contents lists available at ScienceDirect

Acta Psychologica

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

# Come to think of it: Contributions of reasoning abilities and training schedule to skill acquisition in a virtual throwing task

Romy Frömer [a,b,*,1], Birgit Stürmer [b], Werner Sommer [a]

[a] *Humboldt-Universität zu Berlin, Berlin, Germany*
[b] *International Psychoanalytic University, Berlin, Germany*

ARTICLE INFO

*Article history:*
Received 9 September 2015
Received in revised form 22 June 2016
Accepted 22 June 2016
Available online xxxx

*Keywords:*
Skill acquisition
Contextual interference
Parameter learning
Generalized motor programs
Reasoning
Individual differences

ABSTRACT

According to Schmidt's schema theory skill acquisition is based on schema formation where multiple learning incidents with varying task features are abstracted to a unifying pattern, the schema. Practice can be scheduled block-wise, with low contextual interference (CI) or randomly, with high CI. The greater effort during high CI training usually results in reduced training success but enhanced retention and transfer performance. In contrast to well-established CI effects for simple tasks, findings for complex tasks are heterogeneous, supposedly due to the detrimental accumulation of task demands. We assumed that in complex tasks, cognitive reasoning abilities might impose a limit upon schema formation and hence the effectiveness of CI. In a virtual overarm-throwing experiment participants practiced target positions at center, left, or right and were retested for retention - at the center position - and transfer with a larger target distance. Although there was no main effect of CI on performance, either in training, retention or transfer, under high CI, training performance was better for participants with higher reasoning ability, as measured with the Raven matrices. This advantage persisted across retention and transfer. Under low CI, reasoning was positively related to performance improvement only in the last third of training. We argue, that variability of practice is a necessary prerequisite for beneficial effects of reasoning abilities. Based on previous findings, we discuss feedback evaluation as a possible locus of the relationship between reasoning and performance in motor skill acquisition.



The acquisition and improvement of skills plays an important role in human life. The term skill covers a wide variety of actions, ranging from cognitive skills, such as doing algebra to motor skills, such as dancing. Most of our skills refer to procedural knowledge enabling us to produce intended effects. Therefore, during skill acquisition we need to explore the relationship between what is done and its consequences. In motor skill acquisition, to understand the underlying pattern of movement parameters and outcomes, actions and their consequences need to be integrated. Understanding these relationships promotes both stable and flexible goal-directed movement patterns and enhances learning. Whereas in simple tasks, actions may just be associated with their outcomes, complex tasks that "[…] generally cannot be mastered in a single session, have several degrees of freedom, and perhaps tend to be ecologically valid" (Wulf & Shea, 2002, p. 186), need more in-depth analysis of the unique contributions of individual parameters and their interactions towards achieving the intended goal. This might explain why findings from simple tasks do not necessarily generalize to complex tasks (Wulf & Shea, 2002). Moreover, this notion suggests that individuals with a higher ability to understand such relationships should be more successful in the acquisition of skills and performance in goal-directed actions.

An influential theory of motor skill acquisition and improvement is Schmidt's schema theory (Schmidt, 1975). Accounting for the storage problem, it holds that specific movements are not stored as specific motor programs, but that classes of movements are represented as generalized motor programs (GMPs). Depending on the task and its current requirements the invariant features of a suitable GMP are specifically parameterized. In many cases preparation of a movement, including specification of the GMP takes place prior to movement initiation and the program is run once it is completed. Parameterization is based on schema information, that is, schemata containing abstract representations of response-outcome rules. Schmidt distinguishes between two kinds of schemata: *recall schemata*, holding rules on parameter specifications and outcomes, and *recognition schemata*, integrating proprioceptive and external sensory information, and outcome information. Whereas recall schemata are used for response production, recognition

* Corresponding author at: Institut für Psychologie, AG Biologische Psychologie, Rudower Chaussee 18, 12489 Berlin, Germany.
*E-mail address:* froemero@cms.hu-berlin.de (R. Frömer).
[1] Institut für Psychologie, AG Biologische Psychologie, Rudower Chaussee 18, 12489 Berlin Germany

http://dx.doi.org/10.1016/j.actpsy.2016.06.010
0001-6918/

schemata are more relevant for response evaluation. For movements of the same class, the abstract representations of parameter specifications and outcomes in the corresponding recall schema allow for transfer, that is, performing new movements that have never been executed before. Schemata are acquired and refined during schema formation. This process is supported by variability of practice, that is, by performing multiple variants of the same class of movements, e.g. throwing a basketball from different positions. Variability enriches information to be abstracted into the schema. This way, representations of schema rules are strengthened; the stronger the schema, the better the transfer to novel tasks of the same class.

The theory of GMPs has repeatedly been challenged (e.g. Newell, 2003). Among others, it was criticized for being unable to explain practice order effects, for example, of presenting task variants during training block-wise or randomized (Merbah & Meulemans, 2011; C. H. Shea & Wulf, 2005). If only the number of variants of a performed task is relevant for schema formation, the organization of task variants should be irrelevant.

In contrast, practice order effects are accounted for by contextual interference (CI). CI is high when several tasks (or variants of a task) are practiced in mixed order, as in randomized training and CI is low, when tasks are learned in isolation, as in separate training blocks. In laboratory settings, high CI often leads to lower initial training success but to better retention and transfer performance than low CI (J. B. Shea & Morgan, 1979).

Several theories attempt to explain CI effects, most prominently the *elaboration hypothesis* (J. B. Shea & Morgan, 1979) and the *reconstruction hypothesis* (Lee & Magill, 1983). The elaboration hypothesis assumes that during randomized training, multiple action plans co-reside in working memory, where they can be compared. This leads to more elaborate and complex representations of the action plans. In contrast, the reconstruction hypothesis assumes that when the condition changes, the motor solution process – finding the correct movement with regard to the goal – must be repeated in actively reconstructing the action plan instead of just rerunning it. This repeated problem solving enhances representations of the action plans.

Whereas for simple tasks there is consistent evidence for CI effects, results are mixed for applied settings and more complex tasks (Barreiros, Figueiredo, & Godinho, 2007). For example, for a basketball free throwing task (Feghhi, Abdoli, & Valizadeh, 2011) reported that training performance was worse for higher CI. However, in a subsequent retention test, the differences between CI conditions vanished. In a clarinet pitch exercise training conducted by (Stambaugh, 2011), differences in performance between high and low CI vanished towards the end of training. Subsequently, performance during retention was lower than at training in the low, but not in the high CI group. Similarly, in a simulation-based training of trouble-shooting skills (de Croock, van Merriënboer, & Paas, 1998), high CI led to lower performance during training, but was beneficial for transfer after training. Interestingly, the beneficial effect was visible only in far, but not near transfer. Thus, CI effects seem to interact with task complexity. Albaret and Thon (1998) tested this interaction in a drawing task without visual control. Participants drew simple or compound shapes whose segment numbers varied between one and four. For the simple version of the task with few segments there was a clear CI effect in retention and transfer. This effect was, however, not found for more complex versions.

Task complexity may affect learning strategies during training. Thus, Opitz and Friederici (2003) showed that while learning a complex artificial grammar, participants changed from similarity-based decisions to rule abstraction. For simple grammars, however, pattern-based learning was sufficient. Transferring this result to the motor domain, motor learning might require both, pattern-based learning of the associations between actions and their outcomes, as well as rule-based integration of a variety of action and outcome information. The latter is more processing intense and resource-dependent and might thus be disrupted by additional efforts required by CI.

Summarizing heterogeneous effects in the motor learning domain, Wulf and Shea (2002) concluded that results from simple tasks do not necessarily generalize to complex tasks and that specific studies about complex tasks are needed. They suggested that increased cognitive demands by CI during skill acquisition improve retrieval and transfer performance, but added, that in complex tasks additional demands might cause overload and disrupt learning. Furthermore, in simple tasks, CI effects are most consistent when motor programs vary, that is, when movements from different classes need to be learned. In contrast, in complex tasks the CI effect is more stable when different parameters of the same motor program need to be implemented; in complex tasks requiring motor programs from different classes might result in overload (Merbah & Meulemans, 2011).

Moreover extensive practice (C. H. Shea, Kohl, & Indermill, 1990) and pre-existing proficiency support CI effects. Participants with higher experience levels (e.g. skilled baseball players) were found to profit from high CI (Hall, Domingues, & Cavazos, 1994), whereas novices showed better performance after low CI training (Guadagnoli, Holcomb, & Weber, 1999; Hebert, Landin, & Solmon, 1996). Moreover, CI works better for older children and adults compared with young children (Farrow & Maschette, 1997; Wulf & Shea, 2002). One problem in those group comparisons is that adults and older children were often more familiar with the tasks examined. In a study using movement patterns unfamiliar to both groups, Pinto Zipp and Gentile (2010) found beneficial effects of low CI across groups. They argued that CI effects depend not only on task features, but also the learning stage, with high CI being detrimental in early learning stages. To summarize, CI effects were found, when task load was low or reduced by extended or previous learning.

Whereas previous studies considered CI effects as contradicting schema theory, we propose that the effects of CI are two-fold. First, CI increases workload. For simple tasks, this promotes more elaborate processing and, as a consequence, memory encoding. Second, for more complex tasks involving parameter adaptation, CI enhances variability of practice in a given time period. Crucially, variability can only facilitate schema formation if participants are able to abstract from the current task and integrate different learning occasions. Randomized schedules enforce abstraction as a consequence of larger trial-to-trial variability than blocked schedules.

At this point, the individual's capability of drawing conclusions from trial-to-trial parameter-outcome information may become crucial. An important variable determining the ability to abstract trial-to-trial information into a unitary pattern is (inductive) reasoning (Heit, 2000). Existing hypotheses about individual differences in CI relate to working memory, not reasoning. We chose to investigate reasoning because this ability covers the identification and use of patterns from a variety of sources and it is highly correlated with working memory (Buehner, Krumm, & Pick, 2005; Kyllonen & Christal, 1990; Süß, Oberauer, Wittmann, Wilhelm, & Schulze, 2002).

Contributions of cognitive abilities to skill acquisition in general are well established. Ackerman (1988) assumed three independent phases of skill acquisition. In the beginning, learning consists of hypothesis testing, which is related to declarative knowledge and, hence, dependent on cognitive resources, such as working memory. Once a solution is established, there is a transition to an associative phase, in which the relevance of cognitive abilities decreases and perceptual speed becomes more important. Finally, once a skill is well established it becomes autonomous and independent of cognitive abilities, being governed by procedural memory and determined by psychomotor abilities (Ackerman & Cianciolo, 2000; Beaunieux et al., 2006).

Woltz (1988) has shown effects of working memory on procedural learning of a cognitive task. Participants performed actions comparable to a monitoring a control panel, which depended on different conditions according to a complex set of rules. Besides referring to cognitive instead of motor skill acquisition, this study did not require the deduction of production rules because the rules were provided in advance. This is