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Review article

Technologies shape sensorimotor skills and abilities

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ABSTRACT

Humans shape their environment more than any other species does, and the environment, in turn, shapes the profile of human skills. In spite of the general specificity of practice of sensorimotor skills, the waxing and waning of specific skills goes along with modulations of a broader range of skills or sensorimotor abilities. This is illustrated by two examples. The first one is the death of handwriting, which is associated with a reduction of the quality of arm-hand motor control in the production of figural movements. The second one is the birth of video gaming, which facilitates performance in a variety of tasks, ranging from airplane piloting to laparoscopic surgery, probably because of improved control of attention, visual orientation, and further changes. These examples also illustrate the ambivalence of many technological changes that nourish social and educational controversies.

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1. Introduction

When the ancestors of *Homo sapiens* appeared on the scenery of evolution, their environment was shaped by nature. In the course of prehistory and protohistory it became more and more man-made, and in the course of history technologies came to emerge at a progressively faster rate. In this essay I sketch the recent dynamics of technologies first and then focus on the consequences for sensorimotor skills and abilities. These concepts will be briefly explained, and the sensorimotor consequences of two cultural developments will be presented in some detail. Both developments are associated with the proliferation of computers. The first one is the "death of handwriting", and the second one is the "birth of video games". These developments go along with a detriment and a gain with respect to sensorimotor abilities, respectively, and thus illustrate the ambivalence of many technological changes.

2. Dynamics of human technologies

Humans are distinguished by their extraordinary capabilities of tool use, which require sensorimotor skills and abilities as well as conceptual knowledge regarding tools and their appropriate handling [54,55]. Tool-use capabilities enable them to shape their own environment to a higher degree than other species can. As the environment changes, the skills and abilities needed for survival change as well. For example, homo neanderthalensis would probably have no chance to survive in present-day Dusseldorf (which is the major city near the Neander Valley), and a present-day businessman of Dusseldorf would not survive in the habitat of the Neander Valley some 10,000 years ago. With such long time

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interval, there is certainly no doubt that survival requires adaptive changes of the profile of individual capabilities.

On a much shorter time scale, Western cultures have seen dramatic technological changes during the last few centuries such as the industrial revolution some 200 years ago. A couple of decades ago, physical load was a major problem at work, and work-related research was concerned with economic procedures in tasks such as bricklaying [4] or carrying loads [3]. Today physical load at work has become a minor problem overall, whereas limitations of motor skills and dexterity have gained importance [40]. During the last few decades, changes became even more dramatic with the diffusion of computer technologies. Motor skills overall lost importance at work, whereas cognitive skills and communication skills became essential [33,51].

By now, information technology has invaded human life not only in countries of North America and Europe with the highest computer and internet penetration rates, but increasingly also in a number of countries of Asia, the Pacific region, and the Middle East. Variations of these penetration rates across countries are strongly related to national income and some other factors such as telecommunication infrastructure [13]. In addition to a cross-country digital divide, there is – though probably shrinking - an age-related digital divide in countries with already high computer and internet penetration rates [17]. The cultural changes that are associated with information technology are so rapid that at some stage aging can justifiably be characterized as alienation: older people live more and more in a world that is quite distinct from the world in which they grew up and in which they had mastered their adult life. Younger people have acquired a set of skills, abilities, and attitudes that facilitates the use of information technology and has become known as computer literacy. Computer literacy is largely acquired during childhood and adolescence in incidental ways and thus depends on the frequency of computer use [2]. Such differences between generations can be seen in many families.

Computer literacy includes both declarative and procedural knowledge about computers and is related to low computer anxiety. Knowledge, values, and attitudes are what one typically has in mind when one thinks about how humans are affected by cultural changes, including technological ones. Sensorimotor skills and abilities, in contrast, are often conceived as being shaped by biology rather than by culture. This way of thinking relies on an inappropriate dichotomy between the mental and the physical. According to recent notions of embodied or grounded cognition (see [5,60] for reviews), cognitive processes are closely related to physical interactions with the environment. Thus, technology-induced changes of cognition might actually be accompanied or even be preceded by changes of sensorimotor skills and abilities. At least with respect to skills, culture has a strong influence on which tasks people practice.

In this essay I claim that the profile of human sensorimotor skills and abilities is indeed shaped by prevalent technologies, and I use two examples to substantiate this claim. The first one is what can be called the "death of handwriting", and the second one is what can be called the "birth of video games". Only the first of these examples is directly related to the topic of this special issue of TINE. The second one is added from the perspective of technology-induced changes of skills and abilities – so it might be skipped by those who prefer to focus on the various aspects of handwriting. The examples are preceded by some remarks on motor skills and their acquisition as well as the distinction between skills and abilities.

3. Sensorimotor skills and abilities

Sensorimotor skills are specific physical interactions with the environment, such as reaching and grasping, writing and speaking, walking and swimming, riding a bike and driving a car, using a hammer and a surgical instrument, etc. Many tasks of everyday and professional life are not "pure" sensorimotor skills, but involve cognition as well. For example, in writing sensorimotor processes are coordinated with linguistic ones [57,86], and each type of process is subserved by some of the activated brain regions [79]. In surgery, sensorimotor skills are required in addition to medical knowledge, with training of sensorimotor skills gaining importance when laparoscopic procedures are at stake [105]. The combined involvement of sensorimotor and cognitive processes in the performance of many tasks blurs the distinction between them. Sensorimotor skills without cognitive involvement at all appear to be rare. For example, concurrent mental arithmetic has been shown to interfere with apparently pure sensorimotor tasks such as filing a metallic item [11,12].

Perhaps the most basic fact about sensorimotor skills is that they gain from practicing them. Practice-related improvements can be observed for various skill characteristics (see [41,42] for brief reviews). First, performance becomes faster. The time to perform a certain action such as making a cigar declines as a power function of the number of repetitions, which is known as the power law of practice [16,38]. Second, performance becomes more accurate. However, whereas a person generally can judge whether performance has been faster or slower than in the preceding trial, this in general is not possible with respect to accuracy. Therefore, to improve accuracy the learner generally needs additional information, augmented feedback or knowledge of results [93,103]. Third, performance often, but not invariably, becomes less variable in the course of practice. Reduced variability can be associated with improved accuracy, as in throwing darts. Fourth, movements tend to become smoother [90]. Fifth, performance mostly becomes more economic. For example, movements are produced with progressively less total muscle activity as practice proceeds [76]. Finally, motor skills tend to become automatic: they can be performed concurrently with several other tasks with reduced or even no interference [71,80], though for some tasks interference likely remains or even increases. The notion of automatization can have additional meanings [74], for example a reduced role of conscious awareness during performance. In fact, directing attention to certain aspects of skilled sensorimotor performance can produce interference [47,109].

Whereas the acquisition of different sensorimotor skills shares a number of properties, the processes, representations, and neural structures involved are heterogeneous (see [45] for review). Across different types of task, there are both task specific and common regions of the brain with increasing activity in the course of practice [37]. In addition to increasing as well as decreasing activity of particular regions of the brain, practice also goes along with a reorganization, that is, a change of brain regions involved. These changes are likely related to plastic changes of functional brain networks, that is, changes of interactions between regions (see [58] for review). After sufficiently long practice, even morphological changes such as increased volumes of gray matter in relevant brain areas have been observed (see [18] for review). On a more fine-grained level, experience-dependent changes of synaptic connections between neurons have been documented [49]. Thus, motor skill acquisition makes use of neuronal plasticity – it changes the structure of the brain at different levels, from synaptic efficiency at a microscopic level to gray-matter volume at a macroscopic level.

The improvement of sensorimotor skills in the course of practice is typically specific to the practiced skill and does hardly or not at all generalize to similar tasks or even to the same task performed under slightly different conditions. This characteristic is known as "specificity of practice". For example, both for simple