Motor skill learning and performance: a review of influential factors

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OBJECTIVES Findings from the contemporary psychological and movement science literature that appear to have implications for medical training are reviewed. Specifically, the review focuses on four factors that have been shown to enhance the learning of motor skills: observational practice; the learner's focus of attention; feedback, and self-controlled practice.

OBSERVATIONAL PRACTICE Observation of others, particularly when it is combined with physical practice, can make important contributions to learning. This includes dyad practice (i.e. practice in pairs), which is not only cost-effective, but can also enhance learning.

FOCUS OF ATTENTION Studies examining the role of the performer's focus of attention have consistently demonstrated that instructions inducing an external focus (directed at the movement effect) are more effective than those promoting an internal focus (directed at the performer's body movements). An external focus facilitates automaticity in motor control and promotes movement efficiency.

FEEDBACK Feedback not only has an informational function, but also has motivational properties that have an important influence on learning. For example, feedback after successful trials and social-comparative (normative) feedback indicating better than average performance have been shown to have a beneficial effect on learning.

SELF-CONTROLLED PRACTICE Self-controlled practice, including feedback and model demonstrations controlled by the learner, has been found to be more effective than externally controlled practice conditions.

CONCLUSIONS All factors reviewed in this article appear to have both informational and motivational influences on learning. The findings seem to reflect general learning principles and are assumed to have relatively broad applicability. Therefore, the consideration of these factors in designing procedures for medical training has the potential to enhance the effectiveness and efficiency of training.

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INTRODUCTION

Motor skills are an essential component of the expertise displayed by, and required of, individuals working in medicine or other health professions. How these skills are taught and practised has changed considerably over the past few years. For example, with the advancement of technological capabilities, training in surgical skills now makes increasing use of virtual-reality simulation[1] and computer-based video instruction.[2] Although some studies have found that additional virtual-reality training can facilitate the transfer of skills to the operating room,[3] others did not find any beneficial effect of prior virtual-reality training on surgical performance.[4] Furthermore, the effectiveness of simulation compared with other methods of medical training has been questioned.[5] Some have made suggestions for enhancing the usefulness of simulator training by combining it with instructional techniques that adhere to learning 'principles'.[6] Yet not all such principles have stood the test of time, as we will argue in this review. More recent findings question some of the traditional assumptions regarding learning.

Some studies examining factors that have been shown to facilitate learning in the cognitive or motor domain, such as the use of repeated testing[7] or summary feedback,[2] have already demonstrated their utility for medical training. Other researchers have begun to compare the effectiveness of different practice schedules in the learning of surgical tasks.[8] The results of these studies are promising. In this review, we highlight some relatively recent findings (i.e. from the past 10 years or so) that we believe also have potentially important implications for medical education. Specifically, we review studies related to observational learning, learners' focus of attention, feedback and self-controlled practice. These factors have consistently been shown to affect skill learning. We argue that the effectiveness of certain practice conditions or instructions is, to a large extent, the result of optimised motivational states of the learner. The role of motivation in learning has, until recently, been largely neglected in the motor learning literature. Consideration of these newer findings in designing procedures for medical training has the potential to enhance performance effectiveness and training efficiency. First, however, we address the distinction between *performance* and *learning*, which has important implications for the interpretation of findings and the design of studies.

LEARNING VERSUS PERFORMANCE

Training in the medical field is expensive. Therefore, finding effective and efficient training methods that can result in cost savings is a legitimate and important motive for many researchers. An intuitive approach might be to compare different practice methods in terms of the time needed by participants to reach a predefined level of performance.[9,10] Such an approach has significant shortcomings, however. It can only demonstrate how performance is influenced by certain training methods, which may, or may not, have anything to do with how much was learned. Learning is typically defined as a relatively permanent change in a person's capability to perform a skill.[11] Therefore, researchers use retention or transfer tests (the latter involve a variation of what was practised) that are performed after a certain time interval (i.e. at least 1 day, but sometimes several days or even weeks). The purpose of this interval is to allow any temporary performance-enhancing effects (such as caused by greater guidance) or performance-degrading effects (such as caused by increased fatigue) that certain practice conditions may have created to dissipate, leaving only the relatively permanent, or learning, effects. Another important aspect of retention or transfer tests is that all groups perform under the same conditions (e.g. without feedback or demonstrations). Only then can the performance of different groups be compared on a level playing field, so that conclusions can be drawn about the effectiveness of different practice methods for learning. In fact, it is not uncommon for practice conditions that facilitate (or prop up) performance during practice to result in less effective learning, and vice versa.[11] Thus, one cannot infer that the most rapid change in performance, or achievement of criterion performance – under practice conditions in which feedback, modelling or other interventions are still present – constitutes true learning in the sense of retained or generalisable skill or knowledge. Clearly, as in other areas, the goal of training in the medical field is not to facilitate performance during practice, but to enhance the *learning* and *transferability* of clinical skills. In the following sections, we review variables that have been shown to affect learning.

LEARNING THROUGH OBSERVATION

Observational practice is often discounted as an effective method to use in the learning of simple and complex motor skills. This notion comes in part from previous findings that observational practice is typically not as effective as physical practice, although it has been consistently shown to be more effective in the learning of motor skills than no practice.[12] Research has shown that observational practice can make unique and important contributions to learning, especially when observation is combined with physical practice.[13,14] Indeed, neuroimaging experiments report that a set of common neural structures are activated during both action production and action observation.[15–17] The shared neural structures include the premotor cortex, supplementary motor area, inferior parietal lobule, cingulate gyrus and cerebellum.

At a behavioural level it is thought that the movement representation and associated processing mechanisms acquired via observation are also mediated by similar processes.[18] This notion is consistent with results that have shown that variables affecting learning through physical practice tend to affect observational learning in a similar way. For example, experiments investigating the effects of schedules of practice,[19,20] sensory information[21] and relative feedback frequency[22,23] on learning have shown similar patterns of results for models and observers. However, Shea *et al.*[24] argued that observation may give the learner unique opportunities either to extract important information concerning appropriate coordination patterns and subtle requirements of the task or to evaluate the effectiveness of strategies that would be difficult, if not impossible, if he or she were to prepare and execute an impending movement concomitantly. From that perspective, observational practice offers the learner a chance to conduct processing that could not occur simultaneously with physical practice.

The role this additional processing can play in learning is best demonstrated when participants alternate between physical and observational practice in dyads (Figure 1). That is, two participants alternate between observing and physically practising the task. In experiments that have used this practice scheme, retention performance has demonstrated the unique contributions of observational practice. On retention tests, participants who practise in dyads perform as well as, or better than, participants who undertake only physical practice, even though the dyad participants undertake only half the physical practice trials that the participants in the physical practice group enjoy.[13,14] In addition, transfer performance following dyad practice tends to be superior to that following physical practice alone. Apparently, the strategies or techniques derived from combined observational and physical practice result in more flexible or generalisable capability. Learning benefits of dyad practice are presumably also a result of enhanced motivation, resulting perhaps from competition with the partner, the setting of higher goals, or the loss of self-consciousness as people fulfil interdependent dyadic roles and find another in the same learning boat. It is perhaps not coincidental that participants in collaborative or cooperative learning situations often anecdotally report more enjoyment than they have experienced when learning alone[25] (see also Feedback, below).

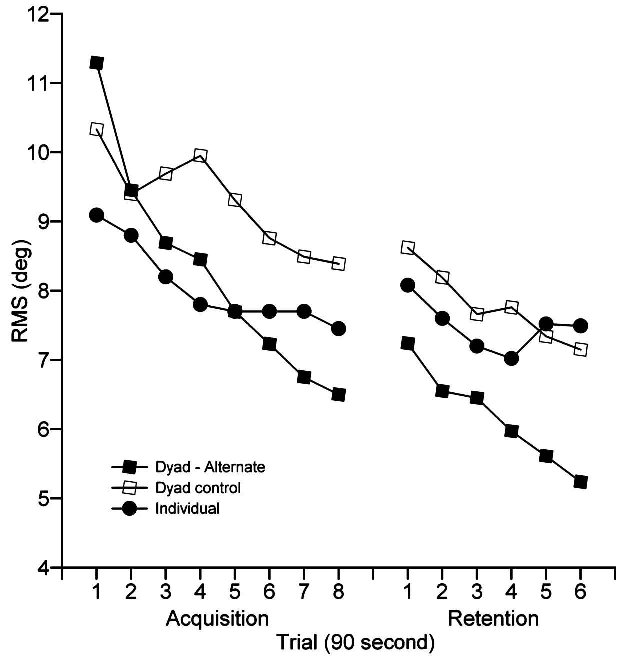

Figure 1 Root mean square (RMS) errors of the individual, dyad-alternate and dyad-control groups during acquisition and retention on a balance task (Shea *et al.* 1999[24]). Participants in the individual group undertook only physical practice. Participants in the dyad groups were allowed the same amount of physical practice, but were also able to observe the other member of the dyad (in the dyad-alternate condition interspersed with their own physical practice trials, in the dyad-control condition before or after their trials). On the retention tests all participants performed individually. (Note: smaller RMS errors indicate more effective performance)

One form of dyadic training is called 'active interlocked modelling' (AIM).[13] Shebilske and colleagues had participants practise a military scenario video game (Space Fortress), such that one partner controlled half of the complex task (e.g. the keyboard), while the other partner controlled the other half (e.g. the joystick).[13] Hands-on practice of one half and observational practice of the other half of the control procedures were switched from trial to trial. Thus, compared with an individual training group in which individuals controlled the whole task on all practice trials, for participants in the AIM dyad, hands-on practice was cut in half. On test games that required control of the whole task there were no differences between groups.

It is important to note that in dyad practice two participants can practise in the time and using the resources that would be required for only one participant using traditional practice. Thus, training efficiency is greatly increased even when dyad practice only results in retention performance similar to that of physical practice. Indeed, Shebilske *et al.*[13] concluded that, by doubling the number of participants trained without increasing the time and other resources necessary, the AIM protocol increased training efficiency by 100% without sacrificing learning effectiveness.

Thus, observational practice – especially when it is combined with physical practice – can make an important contribution to skill learning. Considering the relatively high costs of medical training, the incorporation of video demonstrations, dyad practice or even AIM protocols in simulator training may not only be cost-efficient, but may also have the potential to enhance the effectiveness of training.

FOCUS OF ATTENTION

Instructions and feedback for motor skill learning often involve references to the performer's movements, describing how the movements of certain body parts should be coordinated with those of others in space and time. For example, instructions for tying a knot given to aspiring surgeons may include the following: 'The right index finger and thumb continue to grasp the short end, as the middle and ring fingers are placed behind the short end to begin creating a loop. The left hand has begun to bring the long strand toward the surgeon.'[26] Numerous studies in the past few years have demonstrated that instructions directing attention to performers' movements – and referring to body parts such as fingers, hands, hips, head, etc. (inducing an 'internal focus' of attention) – are relatively ineffective. By contrast, directing attention to the *effects* of the individual's movements on the environment (e.g. an implement) – inducing an 'external focus' – generally results in more effective performance and learning.[27]

Many studies examining attentional focus effects have used complex motor skills. They have shown that a simple change in the wording of instructions can have a significant impact on performance and learning. For instance, despite the fact that club and arm must move in synchrony, instructing golfers to focus on the swing of the club (external focus) has been demonstrated to lead to greater accuracy in shots than instructions to focus on the swing of their arms (internal focus) (Figure 2).[28] Similarly, in basketball,[29] dart throwing,[30] volleyball and soccer,[31] wording instructions in a way that directs attention to the (anticipated) trajectory of the ball or dart, for example, leads to increased movement accuracy compared with instructions that refer to the body part (e.g. hand) producing that effect. For various balance tasks, instructions directing attention, for example, to the support surface (external focus) rather than the performer's feet (internal focus) or no particular focus instructions (control) have consistently resulted in enhanced performance and learning.[32] The advantages of an external focus have been shown for different levels of expertise and populations (including children and persons with motor impairments),[33] as well as for performance under pressure.[27]

An external focus of attention appears to speed up the learning process – or shorten the first stages of learning – by facilitating movement automaticity ('constrained action hypothesis').[34] More specifically, a focus on the movement effect promotes the utilisation of unconscious or automatic processes, whereas an internal focus on one's own movements results in a more conscious type of control that

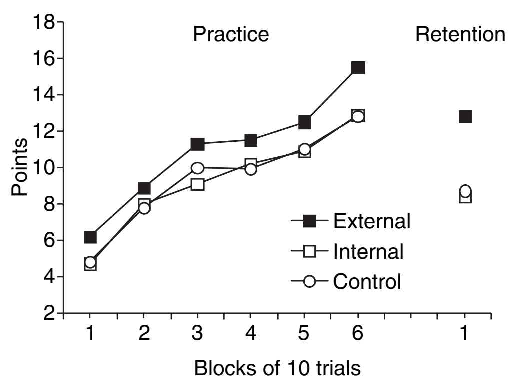

Figure 2 Accuracy scores (higher scores indicate greater accuracy) produced by novice golfers (Experiment 1, Wulf and Su 2007[28]). Participants in the external focus group were instructed to focus on the swing of the club, whereas internal focus participants were instructed to focus on the swing of their arms. The control group was not given attentional focus instructions. During 2 days of practice (with focus instructions and reminders) and on a retention test (without instructions) on day 3, the external focus group outperformed the two other groups

constrains the motor system and disrupts automatic control processes. Support for this view comes from studies showing reduced attentional demands when performers adopt an external as opposed to an internal focus, as well as a higher frequency of low-amplitude movement adjustments, which is seen as an indication of a more automatic, reflex-type mode of control.[34] Furthermore, electromyographic (EMG) activity for the same task has been found to be reduced when participants adopt an external focus[29], indicating that movement *efficiency* is also enhanced.[35] Finally, the mere mention within the internal focus instructions of the performer's body may act to increase self-consciousness, or self-focus, which in turn may lead to self-evaluation and activate implicit or explicit self-regulatory processes in attempts to manage thoughts and affective responses.[36]

These findings would appear to have implications for the training and performance of motor skills that have high motor-control demands and require precisely coordinated movements. A focus on the movements *per se* (e.g. on hand or fingers) would be expected to be detrimental to performance. Instead, directing attention to the effect of the movement (e.g. on the suturing material, implement or incision site) should result in greater effectiveness and efficiency. Specifically what the optimal external focus target might be for a given task and learner experience combination remains an empirical question. To date, however, the fact that the external focus advantage has been found so consistently suggests that investigators have identified reasonable external foci for their various laboratory and real-world tasks.[27]

FEEDBACK

Feedback examined in the context of motor learning research usually involves information about the outcome (termed 'knowledge of results' [KR]) or the quality of the movement (termed 'knowledge of performance' [KP]). The latter corresponds more to the feedback given by an instructor in medical education. Yet, both types of augmented feedback (KR, KP) seem to adhere to the same principles in the way they affect learning.[37] Much research in the motor learning domain has been concerned with the informational function of feedback, which refers to its role of providing information about an individual's performance in relation to the task goal. In this context, studies have addressed issues such as the effect of feedback frequency, timing, accuracy or error estimation. This research has provided important insights into the role of augmented feedback in learning and the findings have been reviewed in various articles.[37,38] A number of recent studies have examined the role of feedback in the performance and learning of surgical skills, such as suturing or knot-tying.[9,10,39] Although the tasks and types of feedback (e.g. instructor feedback) have obvious relevance for medical training, a caveat of such studies is that the amount and type of feedback are often confounded. Therefore, studies should carefully control the frequency and type of feedback, etc. so that its specific or interactive effects on the learning of clinical skills can be assessed.

Here, we focus on an aspect of feedback that has been largely neglected, or has been assumed to exert only temporary effects on motor performance.[11] Some recent findings indicate that the *motivational* properties of feedback can have an important influence on learning. For example, some studies in the past few years have shown that providing learners with feedback after 'good' trials, compared with after 'poor' trials, results in more effective learning.[40] In these studies, feedback about task performance (i.e. throwing at a target) was provided after each block of six practice trials. However, it was provided on only half of the trials. Specifically, for one group of participants, the feedback referred to the three best trials, whereas, for another group, feedback referred to the three worst trials (unbeknownst to the learners). Participants who received feedback after the best trials demonstrated more effective learning, as measured by retention tests without feedback. Feedback that emphasises successful performance and ignores less successful attempts benefits learning presumably because of its positive motivational effects. Interestingly, learners often have a relatively good feel for how they perform.[41,42] Thus, feedback indicating errors may not only be redundant, but it can also heighten concerns about the self that may hamper learning.[35,36]

Similar self-related concerns, or worries, may be induced by normative feedback. Normative feedback involves information about others' performance, such as a peer group's average performance scores, provided in addition to the learner's personal scores. If such feedback indicates that one's own performance is below average, this may result in decreased self-efficacy (situation-specific self-confidence), negative self-reactions, and decreased task interest.[43] By contrast, positive comparisons with the 'norm' can enhance self-efficacy, produce more positive self-reactions and increase motivation to practise a skill.[44,45] Normative feedback not only has the potential to affect performance while it is provided,[44] but it can have more permanent effects on motor learning. In recent studies, motor learning was enhanced by (false) positive relative to negative normative feedback.[46–48] In one study, two groups of participants practising a balance task were given normative feedback, in addition to veridical feedback about their performance (i.e. deviation of a balance platform from the horizontal), after each trial.[47] In the 'Better' group, participants were led to believe that their performance was better than average, whereas the opposite was the case for the 'Worse' group. On a dual-task transfer test (requiring them to count backward in threes while performing the balance task) without feedback, the Better group demonstrated more effective learning than the Worse group (Figure 3). Thus, the mere conviction of being 'good' or 'poor' at a particular task influenced learning and essentially represented a self-fulfilling prophecy. Interestingly, in another study, feedback indicating better-than-average performance also facilitated learning compared with that in a control group that did not receive normative feedback. The control group's level of learning was similar to that of a group that received negative normative feedback.[48] This finding suggests that positive feedback may have a facilitatory effect on learning. Alternatively, negative normative feedback, or no comparison information (control condition), may trigger thoughts about the self and engage ensuing self-regulatory activities that hamper learning of the primary task.[35,36] Thus, feedback should not merely be viewed as 'neutral' information that is processed – without any affective connotation – with the goal of minimising errors. Rather, the valence of feedback appears to have an influence on motivational processes that, in turn, affect learning.

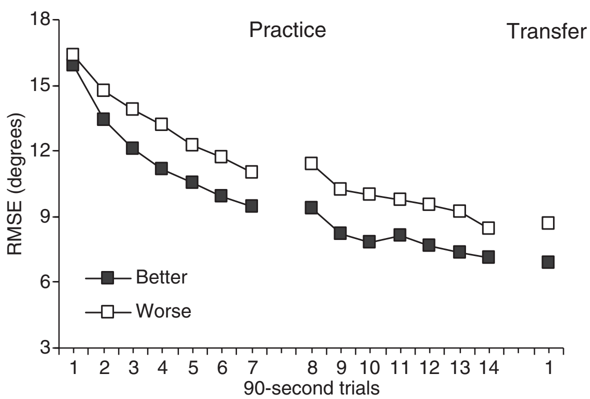

Figure 3 Platform deviations (root mean square error [RMSE]) from the horizontal position for the Better and Worse groups during 2 days of practice, and on the dual-task transfer tests on day 3 in Wulf and Lewthwaite (2009).[47] The 'Better' group showed more effective balance performance on the transfer test. (Note: smaller RMSEs indicate more effective performance)

These findings suggest that instructors in medical training should not only consider the informational function of feedback, but should also remember that feedback will almost certainly affect learners' motivational states. Suggestions such as 'provide immediate (proximate) feedback when an error occurs'[6] should be viewed in this context. Error information may not only be superfluous, as learners may already have a good sense of how well they have performed,[41,42] but it also has the potential to be demoralising. Furthermore, recommendations to provide 'evidence at the end of each trial of progress (graphing the ''learning curve''), with reference to a proficiency performance goal that the trainee is expected to attain'[6] should be viewed with some caution, given recent findings related to normative feedback. Although goal setting has been shown to enhance learning,[49] feedback indicating that performance is below expectations – especially when presented repeatedly – may have negative effects on learning.

SELF-CONTROLLED PRACTICE

In most training situations, instructors determine the details of the training protocol or practice session. They decide, for example, on the order of practice tasks, practice duration, and when or if feedback will be provided or demonstrations given. Thus, whereas teachers generally control most aspects of practice, learners assume a relatively passive role. Yet there is converging evidence that the effectiveness of skill learning can be enhanced if the learner is given some control over the practice conditions. That is, at least a certain degree of self-control can result in more effective learning than completely prescribed training protocols.

For instance, having learners decide after which trial they want, or do not want, to receive feedback has been demonstrated to lead to more effective learning than predetermined feedback schedules. This has been shown in studies using sequential timing tasks[41,50] and throwing tasks.[51,52] Interestingly, the percentage of practice trials on which self-control learners requested feedback varied widely between studies, ranging from 11%[52] to 97%.[50] Although the frequency of feedback requests might depend on the nature of the task, or on the exact instructions given to participants (i.e. to what extent they encourage the learner to ask for feedback), it seems clear that the feedback frequency is less important than the learner's ability to choose, or not to choose, feedback. Self-controlled practice conditions have generally been assumed to lead to a more active involvement of the learner, enhancing motivation and increasing the effort invested in practice.[53,54] Self-controlled feedback might also correspond better to learners' needs for information about their performance, such as after a strategy change, or allow them to ask for feedback after presumably successful (more motivating) trials.[41]

Other studies have found advantages in the self-controlled use of physical assistive devices, compared with yoked control conditions, for the learning of balance tasks.[55,56] These studies gave indications that learners engaged in different information-processing activities, such as a search for the optimal movement pattern, when they had control over the use of the assistive devices. In another study, participants were able to request to view a video of a skilled model performing the task to be learned (basketball jump shot).[57] The results showed that the learning of the movement form was significantly enhanced, compared with that of learners who had no control over the video presentations (Figure 4). Self-controlled learners presumably extracted more, or more relevant, information from the model presentations compared with yoked participants. Alternatively, they may have paid particular attention to aspects of the movement they were uncertain about (e.g. to identify errors or to obtain confirmation that their technique was correct).

Given the advantages of self-controlled practice, it seems safe to suggest that training procedures in medical education should incorporate at least a certain degree of learner control. Allowing trainees to decide, for example, what to practise and when to view a model presentation or receive feedback, would be expected to benefit the learning process because of its advantageous effects on information processing and motivation.

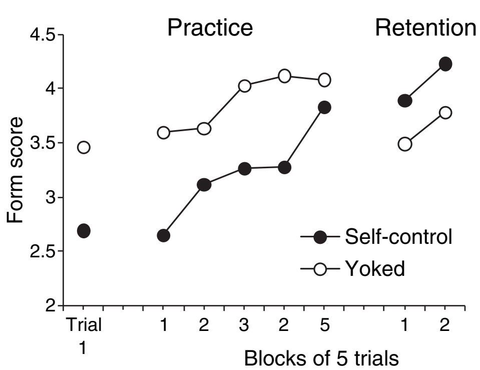

Figure 4 Movement form scores (higher scores indicate more effective form) for basketball jump shots (Wulf *et al.* 2005[57]). Self-control group participants, who had control over the presentation of an expert video model, outperformed yoked group participants – despite an initial disadvantage – on the retention test

CONCLUSIONS

In this review, we have discussed several factors that have been shown to facilitate the learning of motor skills (i.e. observational learning, external focus of attention, positive feedback, self-controlled practice). There are potentially a variety of reasons why these variables are effective. As well as presumably conveying some of their learning benefits by enhancing information-processing activities, these variables also seem to optimise motivational states for learning. For example, observational practice not only provides the learner with information about the goal movement or potential mistakes to avoid, but can also influence goal setting by adding a competitive component to the practice situation. Self-controlled practice caters to individuals' fundamental needs for self-determination,[58] allows them to obtain information when desired or needed, and can provide them with the opportunity to ask for feedback after successful trials. The associated positive effects on learners' motivation are presumably largely responsible for the learning benefits seen with this type of practice. Lastly, an external focus of attention and positive (normative) feedback both tend to reduce the extent to which learners become self-conscious. An internal focus or negative (normative) feedback may trigger thoughts about the self.[35,36] The resulting switching of attention to self-regulatory activity not only taxes available attentional capacity, but also tends to lead to a more conscious control of the movement, degrading the effectiveness and efficiency of performance and learning. Consequently, instructions or feedback that minimise the occurrence of self-related thoughts should result in more effective performance and learning.

Readers may note similarities and distinctions in concepts used in empirical research in motor and cognitive learning as presented in this article and in the philosophical and meta-theoretical perspectives that have been prominent in medical education circles over the last few decades. These common terms include collaborative learning (such as reflected in dyadic learning[24] and small-group, problem-based learning activities[59]) and the kind of movement automaticity described in beneficial terms in this review compared with the positive language devoted to notions of self-regulation, mindfulness and reflective professional practice, and their assumed negative counterparts of mindlessness and automaticity.[60,61] We assume that collaborative forms of motor and cognitive learning may tap into common cognitive and motivational substrates,[59] but that there may be important differences between the desirable automaticity and fluidity of movement[35] described above and a lack of mindfulness in one's overall practice behaviour. Does one really want to become reflective in the midst of making a critical incision with a scalpel, disrupting smooth motor control? Or would it be best to reflect before and after the cutting action on whether conditions have been optimised or on assessing the consequences, respectively? By contrast, there may be value in more careful examination of the assumed similarities and distinctions between the optimisation of effective movement control[35] and effective modes of practice.[60,62,63] Our aim in this review was to stimulate further thought and research in medical education. Studies using tasks that are taught in the medical field, as well as corresponding demonstrations, instructions or feedback, are necessary to examine the transferability of the findings outlined here. Nevertheless, we believe that these findings reflect general learning principles from contemporary psychological and movement science that have relatively broad applicability. Therefore, we would assume that medical training would also benefit from instructional strategies that take into account both informational and motivational influences on learning.

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