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THE MOTIVATIONAL ROLE OF FEEDBACK IN MOTOR LEARNING

Evidence, interpretations, and implications

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Learning new motor skills is a critical aspect of life, and there is little disagreement that feedback and motivation play important roles in this process. Feedback is information about one's performance, usually provided by an external source (e.g., teacher, coach, therapist, computer), by which learners can confirm, adjust, or reorganize not only performance but also knowledge, strategies, conceptions, and views about one's self, abilities, and skills. Feedback is an essential tool to optimize learning and is delivered in many different practical settings. Motor learning contexts can vary from children acquiring new skills in physical education to patients adapting or relearning movements in clinical rehabilitation. Other motor learning contexts involve expert athletes, dancers or musicians improving their skills, professionals learning and refining working skills (e.g., a surgical technique), skill learning in human-computer interactions, among many others, in which skilled performance is expected to develop, adapt, and improve.

After decades of research investigating the informational impact of feedback on the acquisition of motor skills, evolving from a dominance of information processing perspectives (see Swinnen, 1996 for a review), it is now well accepted that feedback is not neutral information to be processed by the learner. Rather, feedback plays a critical motivational role in the learning of motor skills. Congruent with numerous findings showing the impact of feedback on motivation and learning in several different practice environments (e.g., Koka & Hein, 2003), the motivational role of feedback has evolved, after two decades of investigation, into a strong and robust topic of research in motor learning.

Motivation is the disposition of individuals to play, explore, engage, interact, understand, master, and persist in activities, with such behaviors being supported, notably in its intrinsic form, by the interest and enjoyment that accompanies such activities (Ryan & Deci, 2000). Motivated learners demonstrate increased energy, direction, persistence of behavior, and enhanced curiosity that results in more exploratory behavior. In terms of neural activity, motivated learners show patterns of activity in neural networks that support salience detection, attentional control, and self-referential cognition, and higher activation in major dopaminergic pathways or reward brain systems that support memory and learning (e.g., Di Domenico & Ryan, 2017; Wise, 2004).

Numerous experiments from behavioral research suggest that motivational levels can be increased and sustained, but also decreased, by distinct factors, including the type, meaning, and content of feedback. Higher motor performance and learning can result from practice conditions in which the use of feedback increases motivation, helping individuals to build confident and self-determined mindsets. In this chapter, an overview of experimental findings from four different lines of investigation evidencing the motivational impact of feedback on motor learning is presented. Potential underlying mechanisms explaining the observed effects are discussed. Implications of the reviewed findings are also highlighted to identify new research perspectives and guidelines to maximize motor skill learning.

Feedback after successful trials

Over the past two decades, scholars in the motor learning domain have tried to identify and understand when and why learners prefer to receive feedback (e.g., whether it is mainly to confirm good performance or to correct mistakes), and when feedback would be more effective for motor learning (e.g., when informing about trials with relatively small errors or with large errors). In fact, if learners are adequately instructed about what needs to be learned and are typically able to discriminate between "good" and "poor" performance, feedback informing about larger errors would be redundant and probably frustrating, and would potentially decrease motivation and learning. In contrast, feedback provided after more successful trials or that informs learners about the best aspects of performance would perhaps help them to confirm that the movement (or part of it) is correct or on the "right track," guiding them to fine-tune it and potentially increasing motivation and learning.

The first motor learning experiment to look at this question revealed that learners are often effective in estimating their errors and discriminating between good and poor trials, and show a clear preference to receive feedback to confirm successful performance (Chiviacowsky & Wulf, 2002). These findings were followed up by an experiment that examined more directly whether learning is enhanced if participants received feedback mainly after smaller rather than larger errors (Chiviacowsky & Wulf, 2007). Participants received feedback on the best half or on the worse half of trials in each practice block, and the former group demonstrated more effective task learning. Together, the findings of both experiments revealed the important motivational role of feedback in motor learning. Notably, these findings were in contrast with the prevailing theoretical view (guidance hypothesis; Salmoni, Schmidt, & Walter, 1984), according to which feedback provided after larger relative to smaller errors would be more important for the acquisition of motor skills.

Several studies have since endorsed the findings described above in different tasks and populations, showing learners' general preference for receiving feedback mainly to confirm good instead of poor performance (e.g., Fairbrother, Laughlin, & Nguyen, 2012) and that deliberately providing feedback after trials with relatively small versus larger errors facilitates learning (e.g., Abbas & North, 2018). Feedback indicating increased success through use of criteria of "good" performance (e.g., Chiviacowsky, Wulf & Lewthwaite, 2012) or the provision of positive short feedback statements (e.g., Stoate, Wulf, & Lewthwaite, 2012) also benefits motor performance and learning. These and many other studies have advanced the knowledge on the motivational effects of feedback after more successful trials in distinct settings, types of tasks, kinds of measures, moments of practice, and populations.

Feedback after good trials benefit learning because it influences learners' perceptions of competence. Competence refers to the need to feel confident, capable of skillfully mastering challenges, rather than feeling ineffective and incompetent in one's environment, and is considered a basic psychological human need (Ryan & Deci, 2000). The feeling of improving and demonstrating success or competence is considered fundamentally satisfying and motivating (Bandura, 1982). Higher perceived competence can inspire learners to set higher performance goals and increase effort tolerance and attention paid during practice (Locke & Latham, 2006; Themanson & Rosen, 2015). Perceived success is expected to increase self-efficacy, thereby breeding subsequent success (e.g., Iso-Ahola & Dotson, 2014). Feedback after more successful trials can also enhance learners' expectancies for performance, strengthening goal-action coupling, a mechanism suggested to enhance motor learning (Wulf & Lewthwaite, 2016).

Motor performance and learning research has, in fact, demonstrated that feedback after good trials results in increased intrinsic motivation (Abbas & North, 2018), positive affect (Stoate et al., 2012), self-confidence (Badami, VaezMousavi, Wulf, & Namazizadeh, 2012), and self-efficacy (Saemi, Porter, Ghotbi-Varzaneh, Zarghami, & Maleki, 2012). Self-efficacy has been found to be a predictor of motor learning (Chiviacowsky et al., 2012). Thus, different opportunities to confirm successful performance through feedback affects motivation, impacting motor learning in a direction whereby learning is enhanced or undermined when participants' perceptions of competence are respectively increased or reduced.

Choices over feedback

Over the past 20 years, motor learning research has also focused on the effects of providing learners with some form of autonomy support over the learning setting, starting with choices over feedback (Janelle, Barba, Frehlich, Tennant, & Cauraugh, 1997). In such studies, participants are typically allowed to choose when to receive feedback during practice (also called self-controlled feedback) and are compared with a control group that is not allowed the chance to choose. The control group usually receives a "yoked" feedback schedule; that is, matching the feedback schedule requested by the choice group.

The positive effects on motor learning of providing choices over feedback have been verified consistently in diverse types of tasks and different populations, such as young adults (Janelle et al., 1997); children (Chiviacowsky, Wulf, Medeiros, Kaefer, & Tani, 2008); individuals more or less extroverted (Kaefer, Chiviacowsky, Meira Júnior, & Tani, 2014); those with high or low physical activity levels (Fairbrother et al., 2012); individuals with disabilities (Hemayattalab, Arabameri, Pourazar, Ardakani, & Kashefi, 2013); and older adults given the choice to control, or not control, when to receive feedback (Chiviacowsky & Lessa, 2017).

Distinct motivational pathways explain why allowing learners choice over feedback may benefit motor learning. One mechanism concerns the satisfaction of the learners' need for autonomy, experienced when people act according to their own beliefs and values. Autonomy is considered a key element of optimal human psychological well-being, linked with increased intrinsic motivation through the satisfaction of a basic psychobiosocial need (Catania, 1975; Ryan & Deci, 2000). The experience of choice, or the anticipation of the opportunity to choose, has been observed to activate reward mechanisms, increasing activity in corticostriatal regions involved in affective and motivational processes (Leotti & Delgado, 2011). Autonomy can also enhance performance by increasing attention and neuroaffective reactions to performance errors (Legault & Inzlicht, 2013), and has been observed to enhance performance expectancies and positive affect (Lemos, Wulf, Lewthwaite, & Chiviacowsky, 2017). An augmentation in learners' perceived competence and subsequent self-efficacy, even independent of actual performance, can also result from choice or perceived control (Chiviacowsky, 2014).

A second important motivational pathway explaining choices over feedback effects relates to an overlay with learners' competence need. Considering that feedback usually carries competence information to be processed for task learning, allowing choices over feedback enables learners to confirm successful performance when desired, thus increasing motivation and facilitating learning by directly satisfying the learners' competence need. Indeed, motor learning research has established the preferences of learners for receiving feedback, mainly in order to confirm good performance when allowed choice (e.g., Chiviacowsky & Wulf, 2002; Fairbrother et al., 2012). In other studies, participants allowed choice were not only observed to ask for feedback mainly after more successful trials but also showed higher attention (EEG activity) while processing the requested feedback and increased intrinsic motivation relative to no-choice groups (e.g., Grand et al., 2015).

Few studies have tried specifically to disaggregate autonomy from competence motivational effects resulting from practice with choices over feedback. The findings indicate the existence of two distinct pathways, with both playing critical roles in motor learning. In the Chiviacowsky (2014) study, competence was controlled in such a way that both groups were able to confirm successful performance at the same rate, while autonomy was manipulated by comparing choice and no-choice (yoked) groups. Even confirming good performance at the same rate, the choice group reported higher self-efficacy levels and increased learning of the task relative to the yoked group. These findings confirmed that autonomy over feedback results in inherent rewards and a greater sense of agency with the exercise of control, protecting learners' perceptions of competence, thus boosting confidence and increasing motivation and motor learning.

In the Chiviacowsky et al. (2012) experiment, autonomy was controlled in such a way that three choice groups could request feedback at the same rate while competence was manipulated by informing participants different subjective criterion of "good" performance (difficult, easy, or no criteria). While all groups, as expected, asked for feedback mainly after good trials, the group that practiced with the difficult criterion rarely confirmed successful performance. This group demonstrated decreased self-efficacy and task learning relative to the other groups. These findings showed that satisfaction of the competence need is critical to the benefits of practice with choices over feedback and that competence frustration can cause deleterious learning effects, even in the presence of autonomy support. Not surprisingly, participants practicing with choices over feedback but not allowed to confirm good performance, either by being prevented from processing the requested feedback or by not receiving feedback based on performance (e.g., Chiviacowsky & Wulf, 2005), were observed to not take full advantage of practice with choices over feedback.

Although distinct motivational pathways for the effects of choices over feedback have been detected, they probably work in parallel to benefit learning when practice is organized for, and results in, the satisfaction of learners' psychological needs. Thus, providing learners with choices over feedback can satisfy their psychological needs, leading to increased motivation and facilitating motor learning. However, practice with autonomy over feedback that somehow frustrates other learners' needs may decrease motivation, thus harming learning.

Positive comparative feedback

For a number of reasons, including the desire for self-improvement or self-knowledge, people generally evaluate themselves against others or their own past selves. Conceptually, social comparison involves self-evaluation via comparison of outcomes of an individual with those of others (Festinger, 1954), while temporal comparison involves the set of opinions and abilities that constitutes an individual self-description at different points in time (Albert, 1977). In several domains, social and temporal comparisons are considered fundamental sources of information for evaluating one's competences, satisfying the learner's self-evaluation goals (e.g., Brown & Middendorf, 1996).

Given the drive in the human organism to compare and evaluate his/her own competence, opinions, and abilities (Festinger, 1954), alongside the motivational value of feedback in providing such information, motor learning research has looked at the potential benefits of providing learners with positive self-evaluative information through social and temporal-comparative feedback. The impact of comparative feedback on motor learning was first examined in the form of social comparison. Lewthwaite and Wulf (2010) provided two groups of participants with (false) comparative feedback suggesting that their performance was in the top or bottom 10th percentile relative to the average performance of a group of peers, while a third group did not receive comparative feedback. The results showed more automatic control of movement and higher balance learning among the former relative to the other groups. Subsequent studies in young adults reported similar effects on the learning of different tasks (e.g., Wulf, Chiviacowsky, & Lewthwaite, 2010). These positive learning effects were also replicated in other populations, including older adults (Wulf, Chiviacowsky, & Lewthwaite, 2012) and children (Ávila, Chiviacowsky, Wulf, & Lewthwaite, 2012; Gonçalves, Cardozo, Valentini, & Chiviacowsky, 2018). Positive social-comparative feedback was also found to increase muscular stability and efficacy at different task difficulty levels in participants learning the stabilometer balance task (Navaee, Farsi, & Abdoli, 2016).

Previous research suggesting that social-comparative feedback affects motor learning has focused attention on temporal-comparative feedback, a more useful form of information for intervention in practical settings, especially considering the logical nature of performance improvements observed in learning settings. Social and temporal comparisons were observed in other domains to independently influence individuals' evaluations of their own skills (Zell & Alicke, 2009). Temporal comparisons were also seen to be preferred among different age groups relative to social comparisons, with their importance increasing throughout life while the importance of social comparison remained constant (Brown & Middendorf, 1996). Given these observations, Chiviacowsky and Drews (2016) evaluated whether temporal-comparative feedback would also affect motor learning. The results of an experiment using a coincident anticipation-timing task showed enhanced learning among participants who received feedback informing them that their performance had gradually improved across blocks of practice, relative to participants who were informed that their performance had slightly degraded over time. A follow-up experiment using a sport task (i.e., golf putting) showed that positive temporal-comparative feedback also benefits motor learning relative to a control group not receiving comparative feedback (Chiviacowsky, Harter, Gonçalves, & Cardozo, 2019). Similar results were observed in an experiment in older adults learning a timing walk task (Lessa, Tani, & Chiviacowsky, 2018). In this way, similar to findings on social comparison, positive temporal-comparative feedback (i.e., informing participants that their performance is improving over time) can enhance the learning of motor skills in different tasks and populations.

Positive comparative feedback affects motor learning because social and temporal comparisons are pervasive and, therefore, can inform individuals about their standing relative to others or past selves, serving as a means for the development of a positive self-concept (e.g., Cheng & Lam, 2007). Research has demonstrated that young adults reported greater tolerance for sustained effort, enhanced motor learning, and higher perceived competence when informed that their performance was above average or temporally improving across blocks of practice (e.g., Chiviacowsky & Drews, 2016; Chiviacowsky et al, 2019; Lewthwaite & Wulf, 2010). Children similarly reported significantly higher levels of perceived competence, importance of doing well, and persistence related to a task relative to control groups (Ávila et al., 2012; Gonçalves et al., 2018). Older adults who received feedback implying that their performance was better than that of their peers, or informed of temporal self-improvements across blocks of practice, reported being less nervous while balancing or learning a walk timing task and less concerned about their ability (Lessa et al., 2018; Wulf et al., 2012). Hence, positive temporal and social comparative feedback act through motivational pathways while satisfying learner's self-evaluation goals, protecting learners' perceptions of competence, increasing task interest and persistence, and alleviating nervousness or self-related efficacy concerns that degrade performance and learning.

Feedback inducing a learnable view of skills

Research in different domains has attempted to explain why some learners tend to be more focused on task learning, reacting to difficult situations by increasing their effort and seeing mistakes as a natural part of the learning process, while others tend to avoid challenging situations that might demonstrate low ability, striving to demonstrate their abilities by outperforming others and showing less effort and persistence when confronted with errors. The results of this research have shown that specific attitudes usually result from individuals' contrasting views on the learnability of skills or how personal competence is constructed – that is, people's conceptions of ability (Ross, 1989). These distinct conceptions of ability can consider competence as learnable/malleable abilities, with improvements being strongly dependent on effort and learning, or as inherited/fixed capacities that cannot be improved beyond a set limit (Dweck & Leggett, 1988). Critical to note is that such dispositional or induced conceptions of ability can be affected simply by different positive feedback statements provided by teachers, instructors, or coaches, developing these two distinct, adaptive or maladaptive, behaviors.

While research in the psychology domain on conceptions of ability has a long history, few experiments have evaluated whether inducing learnable versus inherent conceptions of ability can affect motor performance and learning, and only a couple of these have looked at feedback effects. In one feedback study, children practicing a soccer-kicking task (Chiviacowsky & Drews, 2014, experiment 1) received positive generic (person-related) feedback statements to induce an inherent conception of ability (e.g., "You are a great soccer player!") or non-generic (process-related) feedback statements inducing a learnable view of the skill (e.g., "Your last kicks were very good!"). After a few blocks of trials receiving these distinct positive feedbacks, participants of both groups received the same negative feedback statement ("Those last kicks were not very good!"), and the authors evaluated the subsequent kicks as a function of the different induced conceptions. Participants receiving feedback that induced the learnable view of skill during practice outperformed participants induced to the inherent view. In another experiment (Chiviacowsky & Drews, 2014, experiment 2), the earlier results were confirmed and extended by observing the learning of throwing beanbags to a target, evaluating the more permanent effects of the manipulated views of skills after 24 hours.

Although still limited and deserving of further research, the findings on feedback to induce a learnable versus an inherent view of skills in motor learning show that even young children are sensitive to these kinds of feedback with respect to their behavior and that not all positive feedback is beneficial for motor performance and learning. Subtle wording differences in positive feedback statements can produce different motivational and learning consequences. These findings are in agreement with those of the Cimpian, Arce, Markman, and Dweck (2007) study, where children who received generic positive feedback while drawing showed more helpless behavior regarding persistence and lower competence self-evaluation when criticized than children who received positive non-generic feedback. The findings are also in line with results from motor learning experiments in which different ability conceptions were induced using instructions (e.g., Wulf, Lewthwaite, & Hooyman, 2013).

The learnable view of skill induced by instructions has been observed to result in lower nervousness levels and concerns about ability reported by adult participants while learning a balance task (Wulf et al., 2013) and higher self-efficacy, task interest, and positive affect levels while performing a pursuit-rotor tracking task (Jourden, Bandura, & Banfield, 1991) than the induced inherited/fixed view of ability. The provision of positive feedback suggesting a learnable view of skill likely affects motor learning via similar pathways, potentially protecting learners against setbacks when exposed to errors or mistakes, a situation frequently encountered in motor skill learning contexts (e.g., Chiviacowsky & Drews, 2014). These learners tend to persist and increase efforts when confronted with errors during practice, while others in the same scenario do not persist and instead respond with helpless behavior. In a recent study looking at the neural mechanisms underlying conceptions of ability-related differences in learning, participants with a fixed view of skills showed stronger "punishment" responses (performance and striatal responses) to negative feedback than participants with a learnable view of skills (Bejjani, DePasque, & Tricomi, 2019). Results of a meta-analysis have indicated that conceptions of abilities are associated with measures of intrinsic motivation in the motor domain (Vella, Braithewaite, Gardner, & Spray, 2016). Thus, different conceptions of ability induced by feedback may distinctly affect learners' motivation, facilitating motor learning when promoting a learnable view of skills.

Conclusions, future directions, and practical implications

In this chapter, four lines of behavioral research showing the motivational impact of feedback on motor learning developed over the past 20 years were reviewed. Consistent with theoretical expectations (Ryan & Deci, 2000), the reviewed findings indicate that positive motivational effects of feedback are mediated by the satisfaction of learners' basic psychological needs, with studies performed to date predominantly confirming the competence and autonomy needs. Higher feelings of autonomy and enhanced perceived competence or expectations of future successful performance have been suggested to trigger dopaminergic responses that enhance memory consolidation and neural pathway development, as well as to strengthen the coupling of goals to actions at several different levels, thus optimizing motor learning (Wulf & Lewthwaite, 2016).

Future research on the motivational impact of feedback in motor learning can not only generalize the findings to different settings (e.g., dance, music, sports, martial arts, physical therapy, medical skills) and populations, but also follow many directions and levels of analysis. For example, research has been developed that mainly observes the impact on learners' competence and autonomy psychological needs. Still lacking experimentation is the potential importance of relatedness-supportive feedback in motor skill acquisition. Social relatedness has been observed to affect motor learning when manipulated through instructions (e.g., Gonzalez & Chiviacowsky, 2018), with positive learning outcomes detected when learners felt genuinely liked, connected, and respected during practice. Thus, feedback provided in a way that emphasizes acknowledgment, caring, and interest in participants' experiences may potentially result in higher motivation and learning relative to feedback disregarding learners' satisfaction of the relatedness need. It is also worth noting that the reviewed findings involved learning mainly at an individual level, with participants practicing the task alone, while motor skill learning is often taught in groups or teams. Hence, further studies could focus on how individuals collaboratively sharing the acquisition of a motor skill in groups may be affected by motivational feedback. The application of neuroscience methods may also help to identify the neural underpinnings of motivational states resulting from feedback manipulation (e.g., Reeve & Lee, 2019).

These findings have applicability in multiple learning settings. As reviewed, the way in which feedback is handled during practice can substantially affect the learning process. Increased motivation and positive effects on learning can be expected when feedback affords opportunities for learners to experience feelings of success and efficacy, supports learners' need for autonomy and competence by allowing choices over the feedback delivery, helps learners to be aware of self-improvements over time through evaluative comparative feedback, and highlights a learnable view of skills or conception of ability. Contrarily, practice conditions in which feedback emphasizes greater errors or mistakes, in which the learner is never allowed to exercise control over the feedback provision, in which feedback does not highlight improvements over time, and which induce an entity or fixed view of skills most certainly decrease learners' motivation and impair learning. Observing the interplay between motivational feedback research and real-world learning settings may allow more efficient practice methods to be designed, thus answering several specific problems in intervention (e.g., Winstein, Lewthwaite, Blanton, Wolf, & Wishart, 2014). Understanding how the type, content, and meaning of feedback can influence motivation and learning may allow professionals in many contexts to develop more effective learning environments.

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