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The effects of reward and punishment on motor skill learning

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Abstract

Motor skill learning consists of improvement in two main components: action selection and action execution. Although sports' coaching identifies reward and punishment as having important but dissociable effects for optimising motor skill learning, it is unknown whether they influence selection and/or execution. In addition, whilst current laboratory-based motor skill tasks have investigated the impact of reward and punishment on learning, they have failed to distinguish between improvements in these components. To examine how reward and punishment may impact selection and execution, we discuss their effects in cognition and motor control. We highlight several similarities between these results and those reported in sports coaching and laboratory-based motor skill learning. However, to fully understand these links, we believe novel laboratory-based motor skill learning tasks that allow the effects of reward/punishment on selection and execution to be examined independently are required.

Highlights

- Reward and punishment have dissociable effects on motor skill learning.
- Motor skill learning involves action selection and action execution.
- Other disciplines reveal reward/punishment effects on selection and execution.
- Reward/punishment effects on selection and execution in motor learning are unknown.
- New motor learning tasks must separate selection and execution.

Introduction

Humans possess a remarkable ability to learn new motor skills [1]. Underlying this ability is a complex network of systems mediated by numerous different brain regions [2]. The sensitivity of each of these systems is likely differentially modulated by the rewards and punishments that arise as a result of motor output [3,4]. Although there are various heuristic rules in the field of sports coaching which are thought to represent the optimal strategies for implementing reward and punishment [5], the scientific basis for these is not clear. In this opinion article, we examine the manner in which reward and punishment could affect specific components of motor skill learning and propose future experiments that may help elucidate some of the many remaining questions.

What is motor skill learning?

To begin with, we outline our definition of skill (Box 1). Motor skill learning is a relatively slow process that results in improvements in performance above baseline levels [2]. This improvement can be achieved through two main components. The first is through developing an overall understanding of the task environment in which learning what-to-do-when is critical (knowledge of facts), which we refer to as action selection [6]. The second is through increasing precision of the selected action, referred to here as action execution and measured by motor acuity [6,7] (Figure 1).

Box 1: Components of motor skill learning

Although the term 'motor skill learning' is widely used in the literature, the exact meaning is unclear. One point of general agreement is that the learning of a motor skill should result in a shift of the speed-accuracy trade-off of performance of that skill [28]. However, such improvements could be made in multiple ways. Although in this article we have made a distinction between 'action selection' and 'action execution', these may not be two entirely separable processes. Diedrichsen and Kornysheva (2015) [29] refer to an intermediate stage between selection and execution that incorporates the use of combinations of motor 'chunks' into skilful actions. It remains to be seen how the principles described in the current article apply to this process with this being a vital area of future research. It is also important to note that even in the action selection stage we refer to here may be comprised of more than one system. In the field of cognition, both a model-free and model-based system are proposed [18]. For simplicity, when we refer in this article to 'action selection' we do not attempt to discriminate between these two systems or make claims about the implicit or explicit nature of the selection of actions. For a true understanding of the effects of reward and punishment on motor skill learning, researchers should attempt to at least address which of these many processes the feedback may be affecting.

Reward and punishment within action selection

Thus, part of skill learning depends on knowledge-based selection of the correct actions [6], e.g. learning to select a specific shot in basketball at the correct point in the game (Figure 1). Although action selection processes have rarely been studied in the context of complex motor tasks, there is a vast literature which probes action selection during cognition-based paradigms. Using a broad spectrum of tasks (economic decision-making, two-armed bandit, go/no-go, reversal learning), it has been shown that human participants can treat reward and punishment as distinct categories of events

[8]. However, behavioural differences between reward and punishment are mainly observed during the process of choosing an action among a predefined set of options (e.g., economic decision-making task) [9-11], rather than the process of learning/estimating action values through trial-and-error/reinforcement learning (e.g., two-armed bandit task) [12].

For example, within economic decision-making participants consistently display loss aversion whereby they tend to avoid choices that lead to loss, even when accompanied with the opportunity to receive equal or larger gains [9-11]. In addition, economic and go/no-go decision-making tasks have revealed that action selection is biased by inherent Pavlovian biases which promote action towards reward and inaction in the face of punishment [13-16]. As a result of these biases, participants find it significantly harder to choose options which involve initiating an action to avoid punishment or inhibiting an action to obtain reward [14].

In contrast, healthy participants exhibit similar reward and punishment-based learning during trial-and-error/reinforcement learning tasks [12,17]. Despite this, reward and punishment appear to activate partially separable brain systems [18]. Whereas reward engages dopaminergic frontostriatal circuits [19,20], punishment is associated with activity changes in both the striatum and insula [12,21-24]. To complicate matters, the definition of reward and punishment is highly dependent on a participant's previous experience, referred to as their reference point [9,21]. For example, within a punishment context, successful punishment avoidance can be coded as a reward both behaviourally and at a neural level where the brain's response shifts from the anterior insula (associated with punishment) to the ventral striatum (associated with reward) [25]. The value and importance of this reference point can be altered by task instructions and feedback [25-27].

Reward and punishment within action execution

Although a complex story, it is clear that reward and punishment can have dissociable effects on action selection, but what about action execution? The improvement in action execution (motor control) is generally characterised by a shift in the speed-accuracy trade-off (Box 1) [28,29], i.e., an ability to perform the action both faster and more accurately. It has been shown that for saccades, the potential of reward can induce shifts in the speed-accuracy trade-off in the absence of learning [30-32]. Specifically, in monkeys and humans, saccades made in rewarded directions show decreased variability and latencies despite increased velocities [30-33]. These temporary improvements driven by prospective reward were muted in Parkinson's disease, suggesting an important role for dopaminergic circuits in this effect [33]. Despite a paucity of research, it appears that similar reward-based shifts in the speed-accuracy trade-off are observed in reaching movements [34]. Hence, if action execution improvement is measured by a shift in the speed accuracy trade-off, do we need to redefine this to include a shift outside of the normal range, including reward, and one that persists even when the reward is removed? At present it is unknown whether punishment has a similar effect on action execution. However, in the field of eye-blink conditioning, a correctly timed response is acquired in order to avoid punishment [35,36], suggesting punishment can lead to timing-based improvements in action execution. In spite of this work, indicating that reward and punishment can individually affect some aspects of action execution, it is currently unknown whether reward and punishment have dissociable effects on action execution.

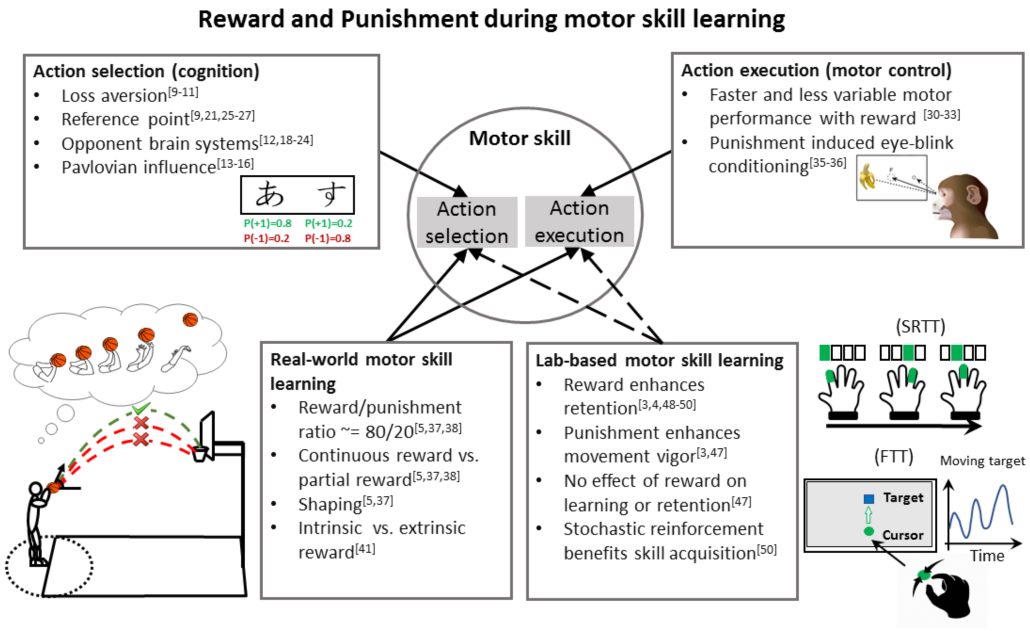

Figure 1: **The effects of reward and punishment on motor skill learning**. Motor skill learning consists of improvement in two components: action selection and action execution (centre). A vast literature that probes action selection during simple cognition-based paradigms has shown dissociable effects of reward and punishment (top-left). In terms of action execution, studies have shown that potential reward enables participants to perform an action both faster and more accurately (top-right). Although this evidence shows that reward and punishment influence both action selection and execution when examined independently, it remains unclear how this relates to motor skill learning. Real-world motor skill learning requires both selection and execution (bottom-left). For example, an ideal basketball shot requires both selecting the best aim angle and optimally executing the chosen angle (bottom-left). Despite sports coaching highlighting the importance of reward- and punishment-based feedback, it is currently unknown whether they influence selection, execution or both. In addition, current lab-based motor skill learning tasks (bottom-right) have investigated the influence of reward and punishment-based feedback on task performance however, they have failed to distinguish improvements in these two components. We believe that novel laboratory-based motor skill learning tasks that enable the effects of reward and punishment on selection and execution to be examined independently are required.

Real world motor skill learning

Although there is evidence that reward and/or punishment influences both action selection and execution when examined independently, it remains unclear how this relates to motor skill learning. Sports' coaching provides a good example of the perceived importance of reward and punishment feedback for motor skill learning within a real-world environment. Coaching manuals describe how a coach should use a combination of reward and punishment to optimise changes in an athlete's performance [5]. In fact, numerous strategies are proposed for implementing reward and punishment within coaching [5,37,38] which as evidence provide a short description of classic operant conditioning literature [39]. However, little laboratory-based research has attempted to directly test these theories.

In terms of reward, there is a belief that it should be provided immediately with every instance of the behaviour being rewarded in the early stages of learning (continuous reward). After the bond between good behaviour and reward is formed, reward should be provided stochastically (partial reward) [5,37,38]. In addition, skills should be broken into segments with reward being based on small improvements of these segments (shaping) [5,37]. One interesting question is whether these behavioural improvements achieved by reward-based shaping have underlying similarities with the reward-driven shifts in speed-accuracy trade-offs [33,40]? A clear distinction is also made between intrinsic (enjoyment/satisfaction) and extrinsic (trophies, money) reward, with it being suggested that external reward can have positive and negative effects on intrinsic reward [41].

With regard to punishment, it should only be provided sparingly (80% reward - 20% punishment rule) [5,37,38]. Although there is agreement that punishment can be effective in decreasing unwanted behaviour, it can also have undesirable side effects. For example, if used excessively it can promote the fear of failure which can in turn increase the likelihood of failure (choking) [5,37,38]. It is possible that the principles of loss aversion and Pavlovian biases described in the field of decision-making [9-11] are highly relevant to these coaching principles. In addition, rather than using aversive punishment (adding something aversive) a more effective form of punishment is 'response cost' (removal of something positive) [37,38]. Again links between this coaching rule and the different ways in which punishment is perceived in cognition (substantive punishment vs. omission of reward) [21] have yet to be studied.

Therefore, if motor skill learning involves improvements in both action selection and execution [6], then the fundamental question is how these observations during real-world motor skill learning, regarding the optimal implementation of reward and punishment, relate to the work carried out within the domains of action selection (cognition) and action execution (motor control) (Figure 1)? Does reward- and punishment-feedback purely affect an athlete’s ability to select the optimal action or can they also enhance an athlete’s capacity to execute the selected action with more precision? To answer these questions, we believe that laboratory-based motor skill learning tasks need to be developed that allow the influence of reward and punishment on selection and execution to be examined independently.

Laboratory-based motor skill learning

Surprisingly few studies have investigated the influence of reward and punishment during laboratory-based motor skill learning. Although there is work which has examined the effects of reward and punishment in motor adaptation [42-46], we will not discuss these here as adaptation is generally thought as an independent mechanism to motor skill learning [2,29].

First, using a serial reaction time task (SRTT) monetary punishment was found to decrease reaction times globally whereas reward led to specific improvements in learning of the sequence [3]. fMRI revealed that reward related improvements in procedural learning was associated with activity in the striatum, whereas punishment led to activation in the inferior frontal gyrus and the insula, similar to what has been described in cognitive decision-making [12,19]. In a force tracking task (FTT) it was found that, in comparison to both punishment and neutral feedback, monetary reward led to enhanced retention and offline memory gains [4]. In contrast, Steel et al., (2016) [47] found little effect of reward on learning or retention in either a FTT or the SRTT. In addition, the authors found punishment led to faster reaction times in the sequence learning blocks, which contrasts to the non-sequence-related speeding of reaction times found by Wächter et al., (2009). In the FTT [47], punishment led to an impairment of performance assessed before and after training which again diverges from the results of Abe et al., (2011) [4].

Finally, using a sequential visual isometric pinch task (SVIPT) it has been shown that reward-based improvements in motor skill behaviour are associated with a frontostriatal circuit [48,49], and are more beneficial if reward is provided in a stochastic manner [50]. This suggests a possible link to the ‘partial reward’ approach to coaching [5,37,38] and the involvement of the same reward-related brain areas involved in cognition-based action selection [22,23].

Although interesting, it is difficult to make any firm conclusions regarding the influence of reward and punishment in laboratory-based motor skill learning. We believe this is due to the use of a range of experimental tasks which are loosely termed ‘motor skills’ without a great deal of understanding as to what exactly each task was measuring. Each of these tasks could involve improvements in both action selection and execution [6]. As these studies examined the impact of reward and punishment during a participant’s initial encounter with a skill, it is unclear to what degree these improvements occurred through action selection and/or execution. Therefore, such experimental designs are currently unable to determine the exact process reward and punishment are influencing.

Future direction

In order to provide a clearer understanding of how reward and punishment influence motor skill learning, we believe laboratory-based tasks need to be developed that specifically isolate the action selection and execution parts of motor skill learning. We accept that this is not an easy challenge as skill learning involves the interplay between these two components, and the balance of the two may vary considerably as learning progresses [29]. However, approaches which enable measuring the selection and execution process separately [33] or designs in which they are separated in time would help elucidate the process being affected.

In future, laboratory-based tasks could be developed that encompass two independent stages in which reward and punishment are based on either a participant’s ability to select the appropriate action or their capacity to execute that action. For example, an experiment could be centred on the game of golf in which participants aim to select the optimal shot to play, analogous to the role of a caddie, and then attempt to successfully execute that selected action, the role of the golfer. Within this task, the impact of reward and punishment could be compared across scenarios in which participants select and execute the action (caddie + golfer), only select the action (caddie) or only execute the action (golfer). It follows that questions for future work include: how does reward and punishment feedback influence the action selection and execution components of motor skill learning? Is a coach’s primary role to provide motivation for increased practise [51], to inform athletes on which actions to perform when [52], to improve the execution of specific components of an action or a combination of all?

Conclusion

Although real-world (sports) and laboratory-based motor skill learning is differentially affected by reward and punishment, the results are often difficult to interpret and the underlying mechanism is unknown. We suggest that reward and punishment could be acting on either action selection, action execution or both. We believe the development of novel motor skill learning tasks that allow the impact of reward and punishment on selection and execution to be dissociated will enable a more coherent understanding regarding the effects reward and punishment have on motor skill learning.

Conflict of interest statement

All authors declare that we have no conflicts of interest.

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Noteworthy papers

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Highly influential paper indentifying the importance of action selection during skill learning.

14. Guitart-Masip M, Huys QJ, Fuentemilla L, Dayan P, Duzel E, Dolan RJ: **Go and no-go learning in reward and punishment: interactions between affect and effect. *Neuroimage* 2012, **62**:154-166.

Important paper revealing the interaction between instrumental learning and Pavlovian biases during decision-making and reinforcment learning.

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Interesting study showing the importance of a reference point with regard to how a punishment is coded in the brain during decision-making.

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An extremely important study revealing dopamine-dependent non-learning reward-based shifts in the speed-accuracy trade-off.

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A good review of the effects of extrinsic and intrinsic reward in sports coaching.

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