

# The effects of reward and punishment on motor skill learning

Xiuli Chen<sup>1\*</sup>, Peter Holland<sup>1\*</sup>, Joseph M. Galea<sup>1</sup>

<sup>1</sup> School of Psychology, University of Birmingham, UK.

\* Authors contributed equally

## Corresponding author

Joseph M. Galea

Email: j.galea@bham.ac.uk

## **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.

## 36 **Introduction**

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

45

## 46 **What is motor skill learning?**

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

53

### 54 ***Box 1: Components of motor skill learning***

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

70

## 71 **Reward and punishment within action selection**

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

78 [8]. However, behavioural differences between reward and punishment are mainly observed during  
79 the process of choosing an action among a predefined set of options (e.g., economic decision-making  
80 task) [9-11], rather than the process of learning/estimating action values through trial-and-  
81 error/reinforcement learning (e.g., two-armed bandit task) [12].

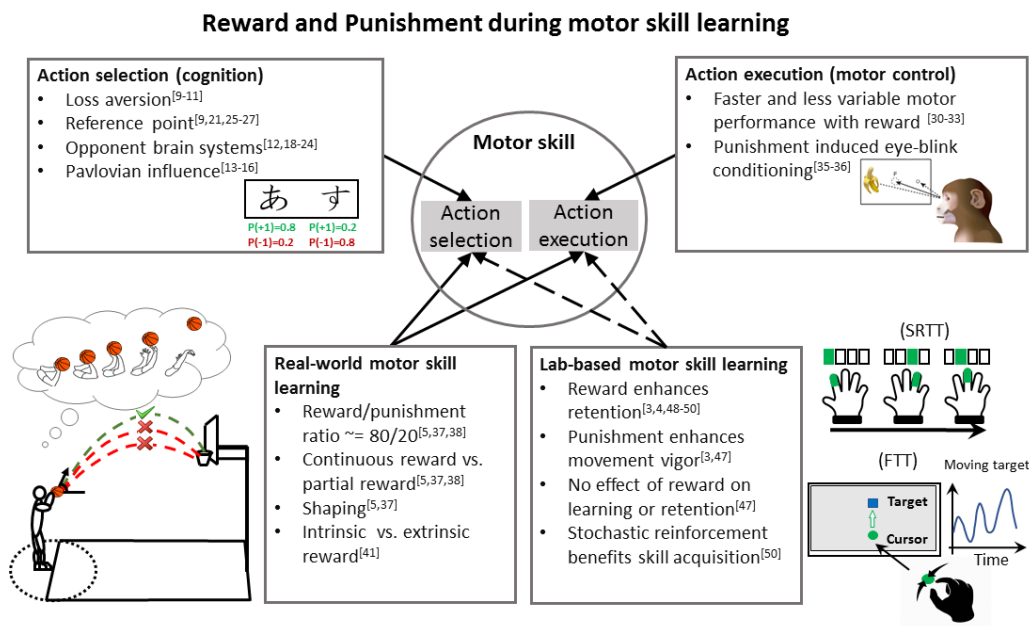
82  
83 For example, within economic decision-making participants consistently display loss aversion  
84 whereby they tend to avoid choices that lead to loss, even when accompanied with the opportunity to  
85 receive equal or larger gains [9-11]. In addition, economic and go/no-go decision-making tasks have  
86 revealed that action selection is biased by inherent Pavlovian biases which promote action towards  
87 reward and inaction in the face of punishment [13-16]. As a result of these biases, participants find it  
88 significantly harder to choose options which involve initiating an action to avoid punishment or  
89 inhibiting an action to obtain reward [14].

90  
91 In contrast, healthy participants exhibit similar reward and punishment-based learning during trial-  
92 and-error/reinforcement learning tasks [12,17]. Despite this, reward and punishment appear to activate  
93 partially separable brain systems [18]. Whereas reward engages dopaminergic frontostriatal circuits  
94 [19,20], punishment is associated with activity changes in both the striatum and insula [12,21-24]. To  
95 complicate matters, the definition of reward and punishment is highly dependent on a participant's  
96 previous experience, referred to as their reference point [9,21]. For example, within a punishment  
97 context, successful punishment avoidance can be coded as a reward both behaviourally and at a neural  
98 level where the brain's response shifts from the anterior insula (associated with punishment) to the  
99 ventral striatum (associated with reward) [25]. The value and importance of this reference point can  
100 be altered by task instructions and feedback [25-27].

101  
102 **Reward and punishment within action execution**

103 Although a complex story, it is clear that reward and punishment can have dissociable effects on  
104 action selection, but what about action execution? The improvement in action execution (motor  
105 control) is generally characterised by a shift in the speed-accuracy trade-off (Box 1) [28,29], i.e., an  
106 ability to perform the action both faster and more accurately. It has been shown that for saccades, the  
107 potential of reward can induce shifts in the speed-accuracy trade-off in the absence of learning [30-  
108 32]. Specifically, in monkeys and humans, saccades made in rewarded directions show decreased  
109 variability and latencies despite increased velocities [30-33]. These temporary improvements driven  
110 by prospective reward were muted in Parkinson's disease, suggesting an important role for  
111 dopaminergic circuits in this effect [33]. Despite a paucity of research, it appears that similar reward-  
112 based shifts in the speed-accuracy trade-off are observed in reaching movements [34]. Hence, if  
113 action execution improvement is measured by a shift in the speed accuracy trade-off, do we need to

114 redefine this to include a shift outside of the normal range, including reward, and one that persists  
 115 even when the reward is removed? At present it is unknown whether punishment has a similar effect  
 116 on action execution. However, in the field of eye-blink conditioning, a correctly timed response is  
 117 acquired in order to avoid punishment [35,36], suggesting punishment can lead to timing-based  
 118 improvements in action execution. In spite of this work, indicating that reward and punishment can  
 119 individually affect some aspects of action execution, it is currently unknown whether reward and  
 120 punishment have dissociable effects on action execution.  
 121



122  
 123 **Figure 1: The effects of reward and punishment on motor skill learning.** Motor skill  
 124 learning consists of improvement in two components: action selection and action execution  
 125 (centre). A vast literature that probes action selection during simple cognition-based  
 126 paradigms has shown dissociable effects of reward and punishment (top-left). In terms of  
 127 action execution, studies have shown that potential reward enables participants to perform an  
 128 action both faster and more accurately (top-right). Although this evidence shows that reward  
 129 and punishment influence both action selection and execution when examined independently,  
 130 it remains unclear how this relates to motor skill learning. Real-world motor skill learning  
 131 requires both selection and execution (bottom-left). For example, an ideal basketball shot  
 132 requires both selecting the best aim angle and optimally executing the chosen angle (bottom-  
 133 left). Despite sports coaching highlighting the importance of reward- and punishment-based  
 134 feedback, it is currently unknown whether they influence selection, execution or both. In  
 135 addition, current lab-based motor skill learning tasks (bottom-right) have investigated the  
 136 influence of reward and punishment-based feedback on task performance however, they have  
 137 failed to distinguish improvements in these two components. We believe that novel  
 138 laboratory-based motor skill learning tasks that enable the effects of reward and punishment  
 139 on selection and execution to be examined independently are required.  
 140

141

## 142 **Real world motor skill learning**

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

152  
153 In terms of reward, there is a belief that it should be provided immediately with every instance of the  
154 behaviour being rewarded in the early stages of learning (continuous reward). After the bond between  
155 good behaviour and reward is formed, reward should be provided stochastically (partial reward)  
156 [5,37,38]. In addition, skills should be broken into segments with reward being based on small  
157 improvements of these segments (shaping) [5,37]. One interesting question is whether these  
158 behavioural improvements achieved by reward-based shaping have underlying similarities with the  
159 reward-driven shifts in speed-accuracy trade-offs [33,40]? A clear distinction is also made between  
160 intrinsic (enjoyment/satisfaction) and extrinsic (trophies, money) reward, with it being suggested that  
161 external reward can have positive and negative effects on intrinsic reward [41].

162  
163 With regard to punishment, it should only be provided sparingly (80% reward - 20% punishment rule)  
164 [5,37,38]. Although there is agreement that punishment can be effective in decreasing unwanted  
165 behaviour, it can also have undesirable side effects. For example, if used excessively it can promote  
166 the fear of failure which can in turn increase the likelihood of failure (choking) [5,37,38]. It is  
167 possible that the principles of loss aversion and Pavlovian biases described in the field of decision-  
168 making [9-11] are highly relevant to these coaching principles. In addition, rather than using aversive  
169 punishment (adding something aversive) a more effective form of punishment is 'response cost'  
170 (removal of something positive) [37,38]. Again links between this coaching rule and the different  
171 ways in which punishment is perceived in cognition (substantive punishment vs. omission of reward)  
172 [21] have yet to be studied.

173  
174 Therefore, if motor skill learning involves improvements in both action selection and execution [6],  
175 then the fundamental question is how these observations during real-world motor skill learning,  
176 regarding the optimal implementation of reward and punishment, relate to the work carried out within  
177 the domains of action selection (cognition) and action execution (motor control) (Figure 1)? Does

178 reward- and punishment-feedback purely affect an athlete's ability to select the optimal action or can  
179 they also enhance an athlete's capacity to execute the selected action with more precision? To answer  
180 these questions, we believe that laboratory-based motor skill learning tasks need to be developed that  
181 allow the influence of reward and punishment on selection and execution to be examined  
182 independently.

183

### 184 **Laboratory-based motor skill learning**

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

189

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

202

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

208

209 Although interesting, it is difficult to make any firm conclusions regarding the influence of reward  
210 and punishment in laboratory-based motor skill learning. We believe this is due to the use of a range  
211 of experimental tasks which are loosely termed 'motor skills' without a great deal of understanding as  
212 to what exactly each task was measuring. Each of these tasks could involve improvements in both  
213 action selection and execution [6]. As these studies examined the impact of reward and punishment

214 during a participant's initial encounter with a skill, it is unclear to what degree these improvements  
215 occurred through action selection and/or execution. Therefore, such experimental designs are  
216 currently unable to determine the exact process reward and punishment are influencing.

217

## 218 **Future direction**

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

226

227 In future, laboratory-based tasks could be developed that encompass two independent stages in which  
228 reward and punishment are based on either a participant's ability to select the appropriate action or  
229 their capacity to execute that action. For example, an experiment could be centred on the game of golf  
230 in which participants aim to select the optimal shot to play, analogous to the role of a caddie, and then  
231 attempt to successfully execute that selected action, the role of the golfer. Within this task, the impact  
232 of reward and punishment could be compared across scenarios in which participants select and  
233 execute the action (caddie + golfer), only select the action (caddie) or only execute the action (golfer).  
234 It follows that questions for future work include: how does reward and punishment feedback influence  
235 the action selection and execution components of motor skill learning? Is a coach's primary role to  
236 provide motivation for increased practise [51], to inform athletes on which actions to perform when  
237 [52], to improve the execution of specific components of an action or a combination of all?

238

## 239 **Conclusion**

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

246

## 247 **Conflict of interest statement**

248 All authors declare that we have no conflicts of interest.

249

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252

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378

### 379 **Noteworthy papers**

- 380 **\*\*6.** Stanley J, Krakauer JW: **Motor skill depends on knowledge of facts**. *Front Hum*
- 381 *Neurosci* 2013, **7**:503.
- 382 *Highly influential paper indentifying the importance of action selection during skill learning.*
- 383 **\*\*14.** Guitart-Masip M, Huys QJ, Fuentemilla L, Dayan P, Duzel E, Dolan RJ: **Go and no-**
- 384 **go learning in reward and punishment: interactions between affect and effect**.
- 385 *Neuroimage* 2012, **62**:154-166.
- 386 *Important paper revealing the interaction between instrumental learning and Pavlovian*
- 387 *biases during decision-making and reinforcement learning.*
- 388 **\*25.** Palminteri S, Khamassi M, Joffily M, Coricelli G: **Contextual modulation of value**
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