Title: Human appetitive Pavlovian-to-instrumental transfer: a goal-directed account

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# Abstract

Pavlovian-to-instrumental transfer (PIT) tasks assess the impact of environmental stimuli on instrumental actions. Since their initial translation from animal to human experiments, PIT tasks have provided insight in to the mechanisms that underlie reward-based behaviour. This review first examines the main types of PIT tasks used in humans. We then seek to contribute to the current debate as to whether human PIT effects reflect a controlled, goal-directed process, or a more automatic, non-goal-directed mechanism. We argue that the data favour a goal-directed process. The extent to which the major theories of PIT can account for these data is then explored. We discuss a number of associative accounts of PIT, as well as dual-process versions of these theories. Ultimately, however, we favour a propositional account, in which human PIT effects are suggested to be driven by both perceived outcome availability and outcome value. In the final section of the review, we present the potential objections to the propositional approach that we anticipate from advocates of associative-link theories, and our response to them. We also identify areas for future research.

A substantial body of research has shown that the presentation of reward-associated stimuli can motivate behaviours that have produced rewards in the past (Hogarth, Dickinson, & Duka, 2010; see Holmes, Marchand, & Coutureau, 2010 for a review). Such *cue reactivity* is thought to play an important role in both adaptive (e.g., searching for food and drink in predictable environments) and destructive behaviours (e.g., overeating, drug-seeking; Hogarth, Balleine, Corbit, & Killcross, 2013), although this has been questioned more recently (Hardy, Mitchell, Seabrooke, & Hogarth, 2017; Hogarth et al., 2018). In this review, we seek to contribute to the debate surrounding the mechanisms that underlie cue reactivity.

Pavlovian-to-instrumental transfer (PIT) tasks are often used to model cue-motivated behaviours in the laboratory (Colwill & Rescorla, 1988; Estes, 1943; Hogarth, Dickinson, Wright, Kouvaraki, & Duka, 2007; Kruse, Overmier, Konz, & Rokke, 1983; Lovibond, 1981; Walker, 1942). Various procedures (further discussed below) are used, but most PIT tasks involve separate Pavlovian and instrumental conditioning phases, followed by a transfer test. During Pavlovian training, neutral stimuli (Ss) are trained to predict different rewarding outcomes (Os), to establish stimulus-outcome (S-O) associations. In a separate instrumental training phase, different responses (Rs) are also trained to produce rewarding outcomes, to establish response-outcome (R-O) associations. In the final transfer test, instrumental responding is then measured (usually in extinction – without reinforcement – to prevent further learning) in the presence of the Pavlovian cues.

Experiments that have employed this three-stage procedure have demonstrated that Pavlovian cues can bias instrumental reward-based behaviours in both a specific (Allman, DeLeon, Cataldo, Holland, & Johnson, 2010; Hogarth & Chase, 2011; Watson, Wiers, Hommel, & de Wit, 2014), and a general fashion (Corbit & Balleine, 2005, 2011; Corbit, Janak, & Balleine, 2007; Quail et al., 2017; Watson et al., 2014). Quail et al. (2017), for example, used an experimental design that is outlined in Table 1. Their participants were given the task of obtaining snack foods from a virtual vending machine. In an instrumental training phase, participants learned to press one button (instrumental response R1) to earn one food outcome (R1-O1), and another button to earn another food outcome (R2-O2). In a subsequent Pavlovian training phase, the participants passively observed the relationship between different coloured lights on the vending machine and various food rewards. Two cues (S1 and S2) differentially predicted the same outcomes earned by the instrumental responses (S1-O1, S2-O2), another cue predicted a third outcome (S3-O3), and a fourth cue predicted no outcome (S4-). In the transfer test, the Pavlovian cues were presented individually and instrumental responding was assessed in extinction.

Quail et al. (2017) observed two effects. First, there was an outcome-specific PIT effect, where S1 and S2 increased choice R1 and R2, respectively. Second, there was a general PIT effect, where stimulus S3 increased the rate of both R1 and R2, relative to a stimulus associated with no reward S4. They therefore observed two distinct forms of PIT. In the outcome-specific case, the Pavlovian stimuli preferentially enhanced the instrumental responses that earned the same outcomes as those signalled by the stimuli. In the general case, the reward-predictive Pavlovian stimulus (S3) elicited an increase in all instrumental responses that earned rewarding outcomes relative to S4, even though those outcomes were not specifically signalled by S3. In real-world terms, this difference can be likened to, for example, a pizza advert that either motivates a person to order a pizza for dinner (specific PIT), or to make dinner arrangements more generally (general PIT).

A related set of studies used, what we refer to as, “single-response” PIT designs. Here, a Pavlovian cue typically increases the rate of a single response that earns a single outcome (Lovibond & Colagiuri, 2013; Lovibond, Satkunarajah, & Colagiuri, 2015; Talmi, Seymour, Dayan, & Dolan, 2008). It is currently unclear whether these single-response PIT effects are predominantly an outcome-specific or general transfer effect (Cartoni, Balleine, & Baldassarre, 2016). We also note that a substantial literature exists on aversive PIT effects in both rats and humans, in which a Pavlovian cue that signals an unpleasant outcome (e.g., shock) potentiates an instrumental response that *cancels* that unpleasant outcome (Campese, McCue, Lázaro-Muñoz, LeDoux, & Cain, 2013; Lewis, Niznikiewicz, Delamater, & Delgado, 2013; Trick, Hogarth, & Duka, 2011), or where an aversive Pavlovian cue inhibits instrumental responding (Geurts, Huys, den Ouden, & Cools, 2013; Huys et al., 2011). It is beyond the scope of this review to provide a detailed overview of the aversive PIT literature; what we aim to provide here is a review of the literature concerning appetitive PIT in humans.

## Automaticity and cognitive control

PIT effects are thought to play an important role in reward-seeking behaviours such as drug-seeking (e.g., Hogarth, Balleine, Corbit, & Killcross, 2013), alcohol use (Garbusow et al., 2016), and compulsive overeating (Colagiuri & Lovibond, 2015). Traditional associative learning theorists often argue that these addiction-based behaviours are automatically triggered by reward-associated cues in the environment (Everitt & Robbins, 2016; Tiffany & Conklin, 2000). These researchers argue that automatic, stimulus-driven models successfully capture the counterintuitive nature of addictive behaviours, in that a person with substance dependence may respond for a reward despite reporting explicit contradictory desires (e.g., buying cigarettes when attempting to quit smoking; Watson, de Wit, Hommel, & Wiers, 2012). Other researchers have argued that such automatic S-R habit models fail to capture the complex nature of reward-based behaviours (e.g., Hogarth et al., 2018). As Robinson and Berridge (2008) point out, real-world drug users are not “S-R automatons”; they often go to extreme lengths to “get their fix”, displaying complex and flexible behaviours that seem to go far beyond the scope of a simple S-R habit. Rather it is that the drug-seeking actions that appear to contradict an explicit abstinence goal (e.g. buying cigarettes when attempting to quit smoking) are the product of the immediate and short term incentives of the drug (e.g. the nicotine “high” and the reduction of withdrawal symptoms) prevailing over the distant and probabilistic outcomes that motivated the alternative goal of quitting (e.g. avoiding the negative health consequences that smoking might cause, such as cancer and emphysema). From this perspective, addictive behaviours appear not to be automatic and inflexible, but rather goal-directed and controlled.

A defining feature of a goal-directed action is that it is voluntarily executed in order to obtain some goal or rewarding outcome. In animal experiments, for example, a hungry rat might press a lever in order to obtain a food pellet. Outside of the laboratory, a child might open a cupboard to reach the biscuit tin. The key point to note here is that, if these behaviours are goal-directed, the rat and the child’s actions should be driven by their pursuit of a rewarding outcome (food pellet or biscuit) rather than by contextual stimuli in their environment. To capture this idea, associative learning theorists have suggested that instrumental behaviours should only be classified as goal-directed if they fulfil two criteria (de Wit & Dickinson, 2009; Dickinson, 1985; Heyes & Dickinson, 1990). First, the *belief* criterion states that actions – for example, the lever-press response (R) – should be based on knowledge that they produce a rewarding outcome (O). Second, the behaviour must satisfy the *desire* criterion, such that the response should be performed preferentially when the outcome is valued as a goal (as for example, food is valued when hungry or water valued when thirsty). Thus, goal-directed actions are learned behaviours that reflect knowledge of both the instrumental (R-O) relationship and the current incentive value of the outcome[[1]](#footnote-1).

## Outcome revaluation and PIT

The outcome revaluation procedure has been the most popular way to assess the goal-directed status of PIT effects. In a typical outcome revaluation procedure, the value of the outcome is reduced (or, less commonly, is increased; see Eder & Dignath, 2016a) after the instrumental training phase but before the critical test phase. If the agent’s actions are affected by this devaluation manipulation (e.g., instrumental actions decrease in frequency for a devalued outcome), then this behaviour is deemed *goal-directed*, since it necessarily meets both the belief and desire criterion. If, by contrast, instrumental responding is not affected by the devaluation manipulation, then the response is typically deemed non-goal-directed, since it instead appears to be driven by the environment rather than the current incentive value of the outcome.

Experiments that have looked at the effect of outcome devaluation on PIT have produced a remarkably mixed pattern of results (at least in humans). Before exploring the possible reasons for these discrepant results, we wish to note that there is a lack of research on general PIT at present, particularly with human subjects. From what research has been done with rats, it seems that general PIT effects are sensitive to outcome devaluation manipulations (Corbit et al., 2007). There is also some evidence in humans that suggests that cues that predict specific foods can have energising effects on responses for other foods (i.e. a general PIT effect), which correlates with hunger levels (Watson et al., 2014). This suggests that outcome value may be important in general PIT. The common interpretation of such evidence is that the general cue elicits an increase in arousal in order to motivate the available responses (e.g. Corbit & Janak, 2007). We refrain from making strong statements on this issue, however, until there are more data to guide our views.

A great deal more research has examined the goal-directed status of *specific* PIT effects, and this is where the heart of the debate lies. To the best of our knowledge, eight experiments with human participants have observed specific, appetitive PIT effects that were insensitive to post-training outcome devaluation manipulations (Eder & Dignath, 2016b, Experiment 2; Hogarth, 2012; Hogarth & Chase, 2011, Experiment 2; Pritchard, Weidemann, & Hogarth, 2017; Seabrooke, Le Pelley, Hogarth, & Mitchell, 2017, Experiment 1; van Steenbergen, Watson, Wiers, Hommel, & de Wit, 2017; Verhoeven, Watson, & de Wit, 2018, Experiment 2; Watson et al., 2014). These studies are in line with animal studies (e.g., Holland, 2004; Rescorla, 1994b), an issue that we discuss in greater depth in the section titled *Remaining issues and areas for future research*. Watson et al. (2014), for example, used the PIT design that is outlined in Table 1, where outcomes O1-O3 were food outcomes (popcorn, chocolate and nuts). For an *outcome devaluation* group, either O1 or O2 was devalued (by allowing the participants to consume the food outcome until sated) immediately before the transfer test. For these participants, one instrumental response was therefore associated with a still-valued outcome, and the other response was associated with a now-devalued outcome. In the subsequent transfer test, both the outcome devaluation group and the control group showed a specific PIT effect, where Pavlovian stimulus S1 increased choice of instrumental response R1 (both paired with outcome O1), and S2 increased choice of R2 (both paired with O2). Importantly, for the outcome devaluation group, the size of the PIT effects for the valued and devalued outcomes did not significantly differ. This null result (as well as other similar findings) was interpreted as evidence that specific PIT effects are largely insensitive to outcome devaluation manipulations. If this finding is taken at face value, it would suggest that specific PIT effects are non-goal-directed effects (according to the traditional instrumental learning definition of goal-directed action).

An equal number of experiments have, however, observed specific PIT effects that were *sensitive* to post-training outcome devaluation manipulations (Allman et al., 2010; Eder & Dignath, 2016a, Experiments 1 and 2; Eder & Dignath, 2016b, Experiment 1; Seabrooke, Hogarth, Edmunds, & Mitchell, 2019; Seabrooke et al., 2017, Experiments 2 and 3; Seabrooke, Wills, Hogarth, & Mitchell, 2019, Experiment 2). Eder and Dignath (2016b), for example, used a traditional PIT procedure, in which instrumental responses and Pavlovian stimuli were trained to predict shared lemonade drink outcomes in separate instrumental and Pavlovian training phases (two different lemonade flavours were used in the experiment – O1 and O2). Immediately before a transfer test, one of the lemonade drinks was devalued by adulterating it to make it taste unpleasant. Importantly, the authors observed specific PIT effects that were sensitive to the devaluation manipulation when the participants consumed the lemonade rewards immediately after each test block (the PIT effect for the still valued outcome was larger than for the devalued outcome). This sensitivity to outcome value was not observed when the participants simply took the rewards home with them. Eder and Dignath's (2016b) results therefore suggest that specific PIT effects are sensitive to outcome devaluation manipulations, at least when the devaluation manipulation is strong and the participants are sufficiently convinced that their actions during the transfer test will have consequences.

## Potential reasons for the discrepancies in the literature

In sum, experiments that have examined the effects of outcome devaluation on human specific PIT effects have produced mixed results. If one simply counts up the number of experiments, there is equivalent evidence for and against sensitivity to outcome value. One additional study by Rose et al. (2018) produced mixed results; a specific PIT effect was sensitive to outcome devaluation when both outcomes were cued per test trial, but not when one outcome was cued. While simply counting the number of experiments is a crude approach, it does highlight that there is a reasonably even mix of experiments that have observed specific PIT effects that were sensitive and insensitive to outcome devaluation manipulations. It is therefore important to evaluate the design characteristics of these experiments in order to identify variables that have potential to explain these discrepancies in the literature. In the section below, we explore the methodological differences between experiments that might underlie the discrepant results.

**Instrumental response schedule.** Instrumental training schedules vary across PIT experiments, which might explain why some specific PIT studies demonstrated sensitivity to devaluation, while others did not. Some experiments use variable ratio schedules, where reinforcement is delivered after a varying number of responses (Seabrooke et al., 2019; van Steenbergen et al., 2017; Verhoeven et al., 2018; Watson et al., 2014). Others use *fixed* ratio schedules, where reinforcement is always delivered after a definitive number of responses (Allman et al., 2010; Eder & Dignath, 2016b). Still others use a forced-choice procedure in which the two instrumental responses are scheduled to be reinforced on a random half of the trials each (Hogarth, 2012; Hogarth & Chase, 2011; Seabrooke et al., 2017; Seabrooke et al., 2018b).

The instrumental training schedule may determine the extent to which instrumental responding might be expected to bring about the outcome, and this is turn may influence the PIT effect, as Pavlovian cues might be inferred to provide information about the efficacy of the response (i.e. goal directed). During specific PIT transfer tests, Pavlovian cues have been suggested to indicate an increase in the efficacy of the associated instrumental action to procure an outcome (Cartoni, Moretta, Puglisi-Allegra, Cabib, & Baldassarre, 2015). From this perspective, variable ratio procedures might be expected to produce more robust specific PIT effects (which are less sensitive to devaluation) than fixed ratio schedules. This is because the Pavlovian stimuli might be expected to exert a greater effect when the instrumental responses are poorer predictors of the outcomes, as is the case with a variable ratio schedule. There is some support for this hypothesis; insensitivity to devaluation has typically been observed with variable ratio schedules (van Steenbergen et al., 2017; Verhoeven et al., 2018; Watson et al., 2014, although see Seabrooke et al., 2019), where the instrumental relationship might be expected to be more uncertain and therefore the PIT effect might be stronger. Conversely, sensitivity to devaluation has usually been observed with fixed ratio schedules (Allman et al., 2010; Eder & Dignath, 2016b, 2016a).

However, both sensitivity and insensitivity to devaluation have been observed with the same instrumental response schedule. Using the same fixed ratio instrumental response schedule, Eder and Dignath (2016b) observed specific PIT effects that were sensitive to outcome devaluation when the lemonade rewards were consumed periodically throughout the transfer test, but not when consumption was delayed. Likewise, Seabrooke et al. (2017) observed insensitivity to devaluation when a single Pavlovian stimulus (S) was presented during the transfer test, but sensitivity to devaluation when multiple Pavlovian stimuli (Ss) were presented (also see Rose et al., 2018). Hence, instrumental schedule does not appear to be a single critical factor, but could be working in concert with other methodological factors to produce PIT effects that are either sensitive or insensitive to outcome devaluation manipulations.

**Devaluation manipulations.** In the specific PIT literature (in humans), outcome devaluation has been achieved by either presenting participants with instructional manipulations to reduce outcome value (Allman et al., 2010; Eder & Dignath, 2016a), by allowing participants to become sated on the outcome (Hogarth, 2012; van Steenbergen et al., 2017; Watson et al., 2014), by adulterating the taste of the outcome (Eder & Dignath, 2016b; Rose et al., 2018; Seabrooke et al., 2017, 2018, 2019), or by presenting participants with health warnings for one of the outcomes (Hogarth & Chase, 2011; Verhoeven et al., 2018). One concern is that these devaluation manipulations may differ in their effectiveness. Eder and Dignath (2016b) were particularly forthright when making this argument. They argued that specific PIT effects might only be insensitive to weak outcome devaluation manipulations. They also suggested that, because participants’ responses are not usually reinforced during the transfer test, there is little cost attached to the participants’ responses (particularly with weak devaluation methods). Of course, researchers test in extinction for good reason, since it ensures that any PIT effect is mediated by prior learning about the Pavlovian and instrumental relationships, rather than new learning about the stimulus-response relationships during the transfer test. Nevertheless, testing without reinforcement (i.e., extinction) could lead to a demand effect, in which participants respond for a cued, devalued outcome because it is perceived to be the “correct” response.

To support the idea that the effectiveness of the devaluation manipulation is important, Eder and Dignath (2016b) showed that a specific PIT effect was sensitive to a strong devaluation manipulation (adulteration of a drink outcome). These authors may be correct that weak outcome devaluation manipulations have less impact on specific PIT effects than strong devaluation manipulations, and their data certainly support this conclusion. However, we would argue that the strength of the outcome devaluation is not the single factor that determines whether specific PIT effects are sensitive to devaluation or not; the same strong devaluation manipulation has been shown to produce both sensitivity and insensitivity to devaluation with different experimental designs (Seabrooke et al., 2017).

**Measurement bias.** We believe that there is a more fundamental, methodological issue that applies to every experiment that has demonstrated specific PIT effects that were insensitive to outcome devaluation manipulations to date. In these experiments, participants learned to perform two instrumental responses to earn different outcomes, before one of those outcomes was devalued. Instrumental responding was then assessed in the presence of Pavlovian stimuli that signalled each outcome, relative to a baseline period. Responding during this baseline period is typically biased towards the valued outcome, which demonstrates that participants’ behaviour, in the absence of any Pavlovian cues, is goal-directed. This baseline bias is important because it has two knock-on effects. First, it reduces the capacity to detect a specific PIT effect for the valued outcome, because baseline responding for the valued outcome is now closer to ceiling (in the extreme case, some participants may be responding for the valued outcome only). Second, it increasesthe potential to observe a specific PIT effect for the *devalued* outcome, because baseline responding for the devalued outcome is now closer to the floor (low responding for the devalued outcome). This means that the specific PIT effect is likely to be underestimated for the valued outcome, since it will be difficult to increase responding above the baseline level. Conversely, the specific PIT effect is likely to be inflated for the devalued outcome, because almost any responding for the devalued outcome will raise it above the baseline level (Seabrooke et al., 2017). Hence, when specific PIT effects for the valued and devalued outcomes are directly compared and do not significantly differ in size, it might simply reflect differences in the sensitivity of the two tests.

Seabrooke et al. (2017, see also Rose et al., 2018) recently examined the effect of outcome devaluation on specific PIT when baseline response choice was balanced. In their Experiment 2, for example, the participants first learned to perform two instrumental responses to earn two unique outcomes each (R1-O1, R1-O3, R2-O2, and R2-O4). One outcome that was associated with each instrumental response (O3 and O4) was then devalued, which meant that baseline response choice in the absence of any Pavlovian cues should have been balanced. In a subsequent transfer test, instrumental response choice was assessed in the presence of compound Pavlovian cues that signalled valued and devalued outcomes that were paired with different instrumental responses (S1+S4 and S2+S3). When baseline response choice was balanced in this way, instrumental choice in the presence of the compound cues was highly sensitive to the devaluation manipulation; the participants selectively avoided responding for the devalued outcomes, despite the presence of an associated Pavlovian stimulus. This experiment therefore suggests that specific PIT effects are sensitive to outcome devaluation when baseline response choice is unbiased.

It might be argued that compound stimuli that predict both valued and devalued outcomes could produce an attentional bias (and consequently a response bias) towards the stimuli that signal the still-valued outcome (an effect known as value-mediated attentional capture; Anderson, Laurent, & Yantis, 2011). That is, Seabrooke et al.'s (2017) effect might not have arisen because baseline response choice was equated, but because the stimulus that signalled the valued outcome captured attention (relative to the devalued outcome). To test this possibility, Seabrooke et al. conducted another experiment where participants first learned to perform two instrumental responses to earn unique rewarding outcomes (R1-O1, R2-O2), and a common rewarding outcome (R1-O3, R2-O3). The unique outcomes O1 and O2 were then devalued, before instrumental response choice was tested in the presence of compound cues that signalled the common valued outcome and one of the devalued outcomes (S1+S3 and S2+S3). Importantly, if response choice was driven by an attentional bias towards the stimulus that signalled the still-valued outcome (S3), then no response bias should have been observed on test, because each instrumental response was paired equally with O3. In fact, a clear avoidance of the cued, devalued outcome was observed. In the presence of the S1+S3 compound, for example, participants showed a bias towards response R2, the response that produced the non-signalled outcome O2. These data suggest that specific PIT effects are sensitive to outcome devaluation manipulations when baseline response choice is balanced.

It might still be argued that both of these experiments were an unfair test of the effect of outcome devaluation on specific PIT. The presence of multiple Pavlovian stimuli (signalling both valued and devalued outcomes) might have encouraged an explicit decision-making strategy (Watson, Wiers, Hommel, & de Wit, 2018), or resulted in a change to the attentional processing of the stimuli. However, Seabrooke et al. (2019) recently tested and provided evidence against these potential explanations. In this experiment, baseline response choice was balanced in the same way as Seabrooke et al. (2017, Experiment 2). That is, two instrumental responses were trained to predict two different rewarding outcomes each (R1-O1/O3, R2-O2/O4), before one outcome that was paired with each response (O3 and O4) was devalued. Importantly, instrumental responding was then assessed in the presence of individual stimuli that had been trained to predict each outcome (S1, S2, S3 and S4). Under these circumstances, specific PIT effects were observed for the valued outcomes (when S1 and S2 were presented), but not the devalued outcomes (when S3 and S4 were presented). When baseline response choice is balanced, then, it seems that specific PIT effects are sensitive to outcome devaluation manipulations, even if only one outcome is cued per test trial.

## Theoretical accounts of goal-directed PIT

On the basis of the analysis presented above, we suggest that the published data favour a goal-directed mechanism for human specific PIT effects, over an automatic, non-goal-directed mechanism, because examples of insensitivity of PIT to devaluation appears to be due to systematic constraints in measurement sensitivity. Although there are several demonstrations of specific PIT effects that were insensitive to outcome devaluation, all of these experiments are problematic in that they assessed the magnitude of specific PIT effects against a biased baseline. We do not, therefore, believe that the data from these experiments constitute strong evidence of an automatic (non-goal-directed) specific PIT effect. This is not to say that the automatic basis of specific PIT effects will not be uncovered in future experiments. We simply argue that, in light of the *existing* data, the most reasonable interpretation is that specific PIT effects are largely goal-directed. In the remainder of this section, we examine the dominant theories of PIT and discuss the extent to which they can account for a goal-directed, specific PIT effect.

**S-O-R theory**. S-O-R is a popular theory of PIT that originates from two-process theories of instrumental learning (Rescorla & Solomon, 1967; Trapold & Overmier, 1972). We refer to S-O-R theory as a “link-based” theory because it assumes that PIT effects are at least partly driven by the operation of automatic links (connections) that allow excitation or inhibition to travel between mental representations (nodes). In this way, we distinguish between the term “associative” as the observable phenomenon of associative learning, and associative links as a theoretical construct (De Houwer, 2009; Mitchell, De Houwer, & Lovibond, 2009). S-O-R theory proposes that PIT effects reflect a chain of associative links that form during the training phases. During Pavlovian conditioning, the participants are suggested to form stimulus-outcome (S-O) links between the mental representations of each Pavlovian stimulus S and outcome O. The instrumental training phase is similarly suggested to produce links between each instrumental response R and outcome O, either as bidirectional R-O/O-R associations (Asratyan, 1974; Elsner & Hommel, 2001; Pavlov, 1932), or as one-way outcome-response (O-R) links (de Wit & Dickinson, 2009; Trapold & Overmier, 1972). The bidirectional O-R/R-O version is consistent with ideomotor theories that suggest that forward response-outcome training allows a response R to become activated whenever an associated outcome O is activated (e.g., Shin, Proctor, & Capaldi, 2010).

According to S-O-R theory, the presentation of a stimulus S during a transfer test leads to activation of the associated outcome O (via the S-O association), which in turn activates and triggers the associated instrumental response R (via the R-O/O-R association). Thus, S-O-R theory suggests that PIT effects reflect a chain of S-O and O-R associative links that form during the Pavlovian and instrumental training phases (e.g., Alarcón & Bonardi, 2016; Alarcón, Bonardi, & Delamater, 2017; Watson, Wiers, Hommel, Ridderinkhof, & de Wit, 2016).

S-O-R theory has received particular attention in recent years because it provides a ready explanation as to why specific PIT effects sometimes appear to be insensitive to outcome devaluation manipulations. The central idea here is that, during a transfer test, the Pavlovian stimulus S activates just the sensory properties of the outcome O, which then triggers the associated instrumental response R (Hogarth & Chase, 2011; Rescorla, 1994b; Watson et al., 2014). Hence, S-O-R theory proposes that specific PIT effects operate via an S-O-R chain that incorporates the sensory properties of the outcome O, but not the current motivational value.

It seems clear that S-O-R theory provides a good theoretical account for the observations of specific PIT effects that were insensitive to outcome devaluation manipulations. It is less clear, however, that S-O-R theory can explain the other experiments that observed specific PIT effects were *sensitive* to outcome devaluation manipulations. This is particularly important if one takes seriously the idea that evidence for insensitivity to outcome value is the consequence of a test using a biased baseline (Seabrooke et al., 2019, 2017), and that, therefore, the evidence supports a goal-directed analysis of PIT (as argued above). Before dismissing S-O-R theory as a model of goal-directed, specific PIT, it is worth considering whether the theory could be modified to explain such effects.

One way that S-O-R theory could be modified is to suppose that when a stimulus S activates its associated outcome O, the value of the outcome is important in determining the response R that is produced (de Wit & Dickinson, 2009; Watson et al., 2018). This model, however, requires some further detail. As far as we are aware, the current body of literature does not provide a clear prediction of the conditions in which outcome value should (and should not) influence behaviour. In particular, a mechanism would need to be described by which activation of the devalued outcome (e.g. O1) suppresses (or fails to activate) the specific response (R1) with which it is associated via the O-R link. The devalued outcome could not simply suppress all responding, as this would affect general PIT, but would not have a specific effect on responses paired with that outcome (i.e. outcome specific PIT). There would need be an account that describes how, in the S-O-R chain, both the sensory properties and the motivational properties operate together to modify responding.

Another approach would be to use the *associative-cybernetic* model of instrumental learning. This model seeks to account for goal-directed behaviour within an associative (link-based) framework (de Wit & Dickinson, 2009; Dickinson, 1994, 2012). The associative-cybernetic model starts with the premise that behaviour is initiated in a habit system that stores stimulus-response (S-R) representations. This habit system does not facilitate goal-directed action on its own because it does not incorporate a representation of the outcome. However, the habit system is thought to interact in complex ways with other systems (that do incorporate outcome representations) to produce goal-directed behaviour. It is possible that the associative cybernetic model, perhaps with some modification, could account for the evidence for goal-directed behaviour in human PIT.

There are, therefore, ways in which an amended S-O-R theory could potentially account for apparently goal-directed, specific PIT effects. However, we emphasise that these are just possibilities that require further articulation. It should be noted that S-O-R theory has been popularised in recent years precisely because it can explain immunity to outcome devaluation manipulations (particularly those seen in non-human animals); in its current form, S-O-R theory predicts insensitivity to outcome devaluation. Therefore, in order for any extended theory to yield testable predictions, theorists would need to make clear the conditions under which one would expect to see sensitivity or insensitivity to outcome devaluation in specific PIT.

**Hierarchical theory.** Hierarchical theory is an alternative theory of specific PIT (Cartoni et al., 2015; Colwill & Rescorla, 1990; Hogarth et al., 2014; Rescorla, 1994a). This account begins with the premise that instrumental conditioning produces a forward response-outcome (R-O) association, as opposed to the backwards O-R association as postulated by S-O-R theory (de Wit & Dickinson, 2009; Rescorla, 1991). During a transfer test, the Pavlovian stimulus S is then suggested to “set the occasion” for the instrumental R-O association. Put differently, the Pavlovian stimulus is suggested to signal that the associated instrumental relationship is effective through a hierarchical S:R-O structure. This hierarchical theory would naturally anticipate that specific PIT effects would be goal-directed, because the forward R-O component suggests that that instrumental responses are performed in order to obtain an outcome, rather than being automatically triggered by an outcome representation (Rescorla, 1994b). Thus, hierarchical S:R-O theory readily accounts for goal-directed, specific PIT effects.

Hierarchical S:R-O theory originates from the animal literature and was traditionally viewed as a link-based theory. Rescorla (1991), for example, suggested that instrumental learning might establish a forward R-O relationship, and the Pavlovian stimulus could then become associated with that relationship. In the transfer test, the presentation of the Pavlovian stimulus is then suggested to signal an increase in the strength of the instrumental relationship. It is relatively straightforward to imagine why a hierarchical S:R-O representation would form as a result of discriminative training, where instrumental R-O relationships are explicitly trained in the presence of Pavlovian cues (e.g., Colwill & Rescorla, 1990). It is less clear, however, why an S:R-O representation would be encoded during a typical PIT procedure, where the Pavlovian and instrumental training phases are kept separate (Seabrooke, Wills, et al., 2019). More recently, some researchers have suggested that the hierarchical structure could be inferential rather than link-based (Hardy, Mitchell, Seabrooke, & Hogarth, 2017; Hogarth et al., 2014; Hogarth & Troisi, 2015). The core idea here is that, during a PIT transfer test, participants *infer* that the Pavlovian stimulus signals which instrumental relationship is most effective on any given trial. This version of hierarchical theory is closely related to a propositional account of PIT, which we expand on further below.

As noted above, the hierarchical model of PIT naturally predicts that specific PIT effects should be goal-directed, and therefore accords with the experiments that observed specific PIT effects that were sensitive to outcome devaluation manipulations. There are also several other lines of support for hierarchical theory. Cartoni et al. (2015), for example, used a typical specific PIT procedure, but manipulated the strength of the instrumental relationships (the Pavlovian cues were reinforced on all Pavlovian training trials). During the instrumental training phase, a low-probability group learned that their instrumental responses were reinforced on 33% of trials. By contrast, a high-probability group learned that their instrumental responses were reinforced on 100% of trials. In a subsequent transfer test, the low-probability group demonstrated a larger specific PIT effect than the high-probability group. Thus, specific PIT was stronger when the instrumental responses were uncertain predictors of the outcomes than when they were perfect predictors of the outcomes. S-O-R theory predicts the opposite result, because the high-probability group should have formed a stronger O-R association (and should therefore have demonstrated a stronger specific PIT effect) than the low-probability group. Hierarchical S:R-O theory, by contrast, successfully predicts the observed result, because the low-probability condition provides more opportunity for the Pavlovian stimuli to signal an increase in the effectiveness of the instrumental relationships during the transfer test.

Further evidence for hierarchical S:R-O theory comes from Hardy et al.'s (2017) recent biconditional discrimination experiment (see Rescorla, 1990, for a similar experiment with rats). Table 2 shows their experimental design. In an initial biconditional training phase, participants first learned to perform two instrumental responses (R1 and R2) in the presence of distinct discriminative stimuli (SD1 and SD2). When SD1 was present, responses R1 and R2 produced outcomes O1 and O2, respectively. In the presence of SD2, these contingencies were reversed; R1 and R2 produced O2 and O1, respectively. Hence, at the end of the training phase, both instrumental responses predicted each outcome equally, but in the presence of different discriminative stimuli. In the subsequent transfer test, instrumental response choice was tested in the presence of one of the discriminative stimuli (SD1 or SD2), plus either a neutral stimulus (S0), or a pictorial stimulus that had been (pre-experimentally) associated with either outcome O1 (S1) or O2 (S2). Consider the example of the SD1 + S1 compound. SD1 was paired with both outcome O1 and O2, while S1 was associated with just O1. Thus, outcome O1 would have been cued more strongly than O2. Under these circumstances, S-O-R theory predicts that the participants should have performed both instrumental responses equally, because each response was paired equally with O1. The hierarchical model, by contrast, predicts that the stimulus compounds should have biased instrumental response choice towards the response that earned the most strongly cued outcome in the presence of the presented discriminative stimulus. The results provided strong evidence of hierarchical control; the SD1 + S1 compound increased choice of the R1 response relative to the neutral stimulus trials.

**Propositional theory.** The final theory of specific PIT that we discuss is a propositional theory recently been put forward by Seabrooke and colleagues (2016, 2017, 2018, 2019, also see Allman et al., 2010 and Hogarth et al., 2014). This propositional theory bears resemblance to the inferential version of the hierarchical model described above, and it is the model that we favour as a theory of goal-directed, specific PIT. The starting point for the propositional theory of PIT is that participants first learn stimulus-outcome (S-O) and forward response-outcome (R-O) relations during the Pavlovian and instrumental training phases, respectively. These associative learning effects are suggested to result from an effortful, cognitively demanding process that produces beliefs about each Pavlovian S-O and instrumental R-O relationship in the form of conscious, verbalisable propositions. These beliefs are then suggested to produce intentional, goal-directed responses during the transfer test. That is, participants are suggested to infer that the presentation of the Pavlovian cues on test serve to signal which outcomes are available, and therefore which instrumental responses will be effective.

The propositional model yields three testable predictions. First, specific PIT effects are suggested to reflect explicit knowledge about the Pavlovian (S-O) and instrumental (R-O) contingencies. Participants who cannot verbalise the Pavlovian and instrumental contingencies should not, therefore, demonstrate PIT effects. This prediction has been borne out in many experiments (Bezzina, Lee, Lovibond, & Colagiuri, 2016; Hogarth et al., 2007; Jeffs & Duka, 2017; Lovibond et al., 2015; Seabrooke, Wills, et al., 2019; Talmi et al., 2008). Of course, these observations do not provide *irrefutable* support for the propositional account of specific PIT. Contingency knowledge might correlate with the magnitude of specific PIT effects without being causally related (Bezzina et al., 2016; Watson et al., 2018). The results are merely more consistent with the propositional account than the link-formation accounts described above.

The second testable prediction that the propositional model makes is that specific PIT effects should reflect controlled actions, and should therefore be highly flexible. The strongest support for this prediction comes from experiments demonstrating that specific PIT effects are affected by post-training verbal instructions. Hogarth et al. (2014) for example, reported an attenuated specific PIT effect among participants who were instructed that the stimuli did not signal which response was more likely to be rewarded before the transfer test. Seabrooke et al. (2016) similarly observed a reversed effect in participants that received instructions stating that the stimuli signalled which response *would not be* rewarded. Furthermore, a number of experiments have reported that the magnitude of the specific PIT effect correlates with participants’ self-reported beliefs that the stimuli signal which response is more likely to be rewarded during the transfer test (Hardy et al., 2017; Hogarth et al., 2014; Mahlberg, Weidemann, Hogarth, & Moustafa, 2019; Seabrooke et al., 2016; Seabrooke, Wills, et al., 2019). Sensitivity to instructional manipulations is consistent with the propositional model because it demonstrates that the instrumental responses that are generated during a transfer test are highly flexible.

Finally, the propositional model assumes that specific PIT effects reflect goal-directed actions that should be sensitive to post-training changes in outcome value. Clearly, the eight experiments that have observed specific PIT effects that were sensitive to outcome devaluation manipulations accord with this position. On the other hand, the remaining experiments that observed specific PIT effects that were *insensitive* to outcome devaluation manipulations are inconsistent with this prediction. However, as noted above, all of these latter experiments are problematic in that they assessed the effect of devaluation on specific PIT relative to a biased baseline. To date, no studies have observed insensitivity to outcome devaluation (in humans) in a specific PIT procedure that equated baseline response choice.

## Remaining issues and areas for future research

Current data suggest that specific PIT is a goal-directed phenomenon. Moreover, we favour a propositional model over an associative link-based model to explain these goal-directed effects, as this model currently provides a better description of the broader human PIT literature base. In this final section, we discuss five criticisms that we anticipate from proponents of link-based theories.

**Translating beliefs into actions*.*** The propositional account emphasises that specific PIT effects are driven by a belief that the Pavlovian stimuli signal which instrumental response will be most likely to produce an outcome on any given test trial. However, the model described above provides no description as to how such a belief translates into observable behaviour. One possibility is that, once the participant has chosen a particular outcome, the action required to obtain that outcome is executed via an ideomotor process (Seabrooke et al., 2016, see also Hommel, 2013). In PIT, the presentation of stimulus S1 suggests that O1 is available. The participant then choses O1 as their goal (if it is valued). Bringing to mind O1 with sufficient vividness then automatically triggers the response (R1) that is associated with that outcome. The key point to note here is that, according to the propositional account, the ideomotor process is not automatically triggered by the mere presentation of the Pavlovian stimulus. Rather, actions are performed once the participant forms an intention to obtain the outcome.

**The irrationality of transfer.** A puzzling aspect of outcome-specific PIT is that, during the transfer test, the Pavlovian stimulus increases the instrumental response that shares a common outcome, even though the stimulus has been trained to produce the outcome on its own (without any need for an instrumental response). As a consequence, outcome-specific PIT effects have been deemed irrational. Some researchers have concluded, therefore, that outcome-specific PIT effects must then be mediated by an automatic S-O-R mechanism (de Wit & Dickinson, 2015). We argue that seemingly irrational effects do not by default necessitate an automatic process. Many human behaviours appear irrational at first sight, but this does not rule out the operation of (perhaps suboptimal) reasoning processes. So, although it might not be entirely rational for a participant to conclude that the Pavlovian stimuli provide information about the availability of the outcome and hence the likelihood that the instrumental response will produce the outcome, it is nonetheless possible to show that these seemingly irrational reasoning processes occur and predict instrumental responding (Hardy et al., 2017; Hogarth et al., 2014; Mahlberg, Weidemann, Hogarth, & Moustafa, 2019; Seabrooke et al., 2016; Seabrooke, Wills, et al., 2019). A goal directed theory of PIT can therefore address this seemingly irrational behaviour: responding is motivated by the combination of outcome expectancy and outcome value, and the presentation of a cue increases the belief that the signalled outcome is available for consumption, and therefore increases the overall motivation to respond for such an outcome.

**Dual-process theories.** It is possible that proponents of link-based theories such as S-O-R theory will argue that our depiction of those theories is overly narrow. For example, associative learning phenomena are often suggested to reflect both the formation of automatic associative links and higher-order propositional reasoning processes. The usual argument here is that the associative link formation mechanism operates in the background, and these automatic processes may only be revealed when propositional processes are consumed elsewhere (McLaren et al., 2014, 2018). Hence, a dual-process version of S-O-R theory would argue that specific PIT effects can be mediated by both a propositional reasoning process and an S-O-R link mechanism (although we note that the propositional component is not the focus of such theories).

We believe that there is a great deal of evidence for the propositional component of this dual-process theory, but less evidence for the underlying automatic component. This is not to say, however, that an underlying automatic component to specific PIT will not be uncovered in future experiments. Most specific PIT experiments train a small number of contingencies that are reasonably easy to learn. It is perhaps not surprising, therefore, that that there is ample evidence of controlled reasoning processes, but less evidence of automaticity. It certainly remains possible that automatic processes will be uncovered in other circumstances, particularly when there is less opportunity for reasoning processes to dominate instrumental response choice. One way to increase the probability of detecting automaticity would be to increase the number of Pavlovian and instrumental contingencies involved, to reduce the likelihood that participants can systematically reason about all of them (for example, see de Wit, Ridderinkhof, Fletcher, & Dickinson, 2013). A specific PIT effect observed in the absence of explicit contingency awareness or outcome expectancy (due to the complexity of the task), would provide a strong challenge to a purely propositional account of human PIT (Lovibond & Shanks, 2002).

An alternative method to investigate the dual process view involves applying cognitive load during a specific PIT test. For example, Seabrooke, Wills, et al. (2019) attempted to uncover automatic processes by applying cognitive load to a variety of different specific PIT tests. Firstly, the simple PIT effect similar to that described in Table 1 was observed under cognitive load, suggesting an element of automaticity. However, the effects observed in more complex designs (involving reversal instructions and multiple outcomes associated with each response) were eliminated by cognitive load.

The effects of cognitive load observed by Seabrooke, Wills et al (2019) could be considered evidence for a dual-processes account: in the case of simple PIT (Table 1), behaviour is largely reliant on automatic processes, but in more complex circumstances (i.e. reversal instructions or multiple cue exposure) controlled reasoning processes are recruited that are vulnerable to cognitive load manipulations. It is important to note, though, that this evidence does not unequivocally support a dual-process account. The resistance to cognitive load observed in simple PIT could simply be because simple specific PIT requires little cognitive capacity. That is, the cognitive load manipulation may not have required sufficient cognitive resources to modify the traditional (simple) specific PIT effect. Importantly, cognitive load reduced the (reversed) PIT effect seen following instructed reversal to chance level performance (Experiment 1, and had a similar effect on the multiple cue PIT effect in Experiment 2). That is, load did not reveal an automatic stimulus-driven PIT effect in the opposite direction to that observed following reversal instructions (there was no reversal of the instructed reversal). Future research should aim to examine the effects of the extent of strong cognitive load manipulations under PIT conditions that are more vulnerable to these manipulations.

**Dissecting double dissociations.** Since a goal-directed account proposes a single-system explanation of specific PIT, it may be argued that evidence of a double dissociation between motivation and outcome responding represents a strong challenge to our argument. Double dissociations have been observed for neural function in specific PIT and general PIT (Corbit & Balleine, 2005, 2011). For example, Experiment 2 of Corbit and Balleine (2005) compared rats with basolateral amygdala (BLA) lesions and rats with central nucleus lesions (CN) to a control group (i.e. rats with sham lesions). They observed that, compared to the control group, rats with BLA lesions did not show a specific PIT effect but did show a general PIT effect. For the rats with CN lesions, general PIT performance was effected but specific PIT performance was similar to controls. This is a double dissociation for the role of BLA and CN function in specific and general PIT, as the neural manipulation (i.e. lesions of the BLA and CN) had opposite effects on performance in each task compared to the control group. There is also evidence for single dissociations for neural function when examining the effects of outcome devaluation on free instrumental responding and specific PIT tasks in animals (e.g. Corbit & Balleine, 2005; Ostlund & Balleine, 2007). For example, Experiment 1 of Corbit and Balleine (2005) observed that rats responded for two different food outcomes to a similar extent during training. A consumption test after a specific satiety manipulation showed that rats in the control (sham-lesion) group, the BLA lesion group, and the CN lesion group consumed more of the still-valued outcome compared to the devalued outcome. However, a specific PIT test showed that the sham and CN group displayed evidence of specific PIT, whereas the BLA group did not observe specific PIT. That is, they observed a single dissociation where destroying the BLA resulted in observing similar performance compared to the sham group on the consumption test but impaired performance on the specific PIT test relative to the sham group. Finally, it should be noted that there is some neuroimaging in humans that shows activation patterns that converge with these animal studies (e.g. van Steenbergen, Watson, Wiers, Hommel, & de Wit, 2017; Prévost, Liljeholm, Tyszka, & O’Doherty, 2012). One may then argue that this body of evidence provides unique support for a dual-process account of PIT. We would argue that such dissociations do not provide unequivocal support for dual-process models. By necessity, these tasks (outcome-specific PIT tasks, general PIT tasks, and outcome devaluation tasks) are not precisely matched; the experimental conditions differ in multiple ways. It is therefore difficult to directly compare any neural correlates that are observed, and it is even more difficult to make strong theoretical claims based on those correlates (Berry, Shanks, & Henson, 2008). Given the differences in task demands, the tasks may well require different types of processing, and the cognitions that take place are therefore likely to require different parts of the brain. It does not follow, however, that these behaviours must be driven by distinct psychological systems that separately generate behaviour (Mitchell et al., 2009). Under a single-system framework, both tasks would be driven by a goal-directed mechanism, but there are peripheral task differences (e.g. the aspects of the task relating to sensation, perception, response generation), not the central learning system, that result in different neural patterns.

We would also like to make the more general point that, while neuroscience experiments (e.g. Corbit & Balleine, 2005, 2011) are useful for testing theories at the neuroscience level, they do not necessarily specify a particular *psychological* model. Rather, we believe the behavioural data tell us which psychological model to choose. In both human and non-human animals, various types of evidence are often argued to *imply* a double dissociation of behaviour observed during specific PIT and outcome devaluation tasks (e.g. Corbit & Balleine, 2005; Ostlund & Balleine, 2007; Hogarth et al, 2011) and between specific and general PIT tasks (e.g. Corbit et al, 2005; Corbit et al 2007; Corbit & Balleine, 2011). However, it is important to note that these observations are not direct evidence of a behavioural double dissociation. They are instead observations of single dissociations of behaviour, where outcome devaluation effects free instrumental responding but not specific PIT performance. Single dissociations cannot be interpreted as unequivocal support for dual process psychological models, because a change in a psychological process might still occur even if this is not observed in task performance (for an elaboration of this debate, see Chater, 2009; Dunn & Kirsner, 1988; Dunn & Kirsner, 2003). In this paper, we have described a single process explanation for how a single dissociation between outcome devaluation and specific PIT might be observed. Moreover, we have reviewed evidence in humans that does not observe the functional dissociation, where instead outcome devaluation also changes performance in specific PIT. Because of this, we have argued that the evidential support for a psychological double dissociation between goal directed and automatic processes in outcome devaluation and specific PIT is weakened. We therefore argue that a single-process system is better suited to account for human PIT data.

**Human and non-human animals.** Finally, this review has focused on PIT studies that have been conducted with human rather than non-human animals. General and specific PIT procedures were first developed in animal experiments (e.g., Corbit & Balleine, 2005), and a number of procedural changes have been implemented to successfully translate these tasks for use in human experiments. For example, in rodent PIT experiments, the transfer test is usually conducted in extinction (without reinforcement). In humans, the transfer test is usually conducted in *nominal* extinction (e.g., Hogarth & Chase, 2011; Watson et al., 2014). This means that, although no outcomes are delivered during the transfer test, the participants are informed beforehand that the outcomes are accumulating, and will be delivered upon completion of the experiment. Researchers typically use nominal extinction procedures because it is difficult to maintain responding in humans in extended extinction sessions. Researchers also use instructions to aid comprehension of the task when running experiments with human participants. Such instructions cannot, of course, be used in experiments with non-human animals. Finally, animal experiments usually use real appetitive outcomes, such as food pellets. Experiments with human participants, by contrast, sometimes use outcomes that are arguably less salient, such as reward “points” (e.g., Hogarth & Chase, 2011) or money (Allman et al., 2010; Eder & Dignath, 2016a).

It might be argued that these procedural differences mean that the human PIT experiments are not really investigating PIT in the pure sense, but rather some other effect that is irrelevant to the PIT phenomenon that is seen in animals. Our first response to this argument is that we see the procedural differences discussed above as positives rather than negatives. If the PIT phenomenon was only seen under the very precise conditions that are used in animal experiments, it would suggest that the effect was rather limited in scope and was probably irrelevant to human behaviour. The fact that PIT effects can be seen in both humans and rodents, using tasks that differ on many parameters, shows that the effect is both general and robust.

It is possible, however, that these procedural differences explain why some experiments with humans have observed (goal-directed) PIT effects that were sensitive to outcome devaluation manipulations. Rescorla (1994b), for example, used the experimental design shown in Table 3 and showed that specific PIT was insensitive to devaluation with rats (for similar results, see Corbit et al., 2007 and Holland, 2004). In this experiment, rats were first given discriminative training, where two stimuli (SD1 and SD2) were trained to predict two rewarding outcomes each when a common instrumental response (Rc) was performed. A further two instrumental responses (R1 and R2) were then trained to predict two of those outcomes each. Importantly, each instrumental response was trained to produce one outcome that was associated with SD1 and another outcome that was associated with SD2. Two of the outcomes, one paired with each discriminative stimulus and instrumental response, were then devalued. In a final transfer test, the rate of R1 and R2 responses was assessed in the presence of each discriminative stimulus. Goal-directed control would have been observed if the rats demonstrated a selective bias towards the response that was paired with the same still-valued outcome as the discriminative stimulus that was presented on test. In the presence of SD1, for example, goal-directed control would have been revealed by an increase in R1 but not R2 responses. This is because both SD1 and R1 were paired the valued O1, whereas SD1 and R2 were paired with the devalued O2. However, Rescorla did not detect evidence of goal-directed control; the discriminative stimuli increased the rate of *both* instrumental responses relative to the baseline periods in which no stimuli were present.

Rescorla's (1994b) results suggest that PIT effects can be insensitive to outcome devaluation manipulations, at least in rats. It is also worth noting that the experimental design should not have produced a baseline bias, because each instrumental response was paired with both a valued outcome and a devalued outcome. In this sense, his study is similar to Seabrooke et al.'s (2019) experiment, in which the baseline was not biased and sensitivity to outcome value was observed. The question then is, why there is a discrepancy between the human and non-human result? One explanation is that there were many procedural differences between the two studies. The Rescorla (1994b) experiments used very complex designs for animals (see Table 3). It is possible that the rats learned that the stimuli and responses produced rewards in general, but did not learn the specific relationships between each stimulus, response and outcome. This could have produced the observed null result. We are also not entirely convinced that the outcomes were sufficiently devalued in Rescorla’s experiment. It was reported that the rats all left “some” of the devalued outcomes, but exactly how many is unknown. If the outcomes were not adequately devalued, this could also have produced the apparent insensitivity to devaluation that Rescorla observed. We suggest that a replication of Rescorla’s results (in both humans and animals) would be a useful first step to progress this debate.

## Conclusion

To conclude, we have argued that the current body of data suggest that, at least in human participants, specific PIT effects are largely goal-directed. These findings, as well as the effects of verbal instruction and the importance of contingency knowledge, present a strong challenge to the traditional associative S-O-R theory of PIT. We favour a propositional account, where specific PIT effects reflect controlled, goal-directed actions that are based on verbalisable knowledge of the Pavlovian and instrumental contingencies. However, we also acknowledge that future research may reveal stronger evidence for an automatic form of PIT, which may be more amenable to associative analysis. We look forward to further research in this area, which will provide an even deeper understanding of the ways reward cues influence reward-seeking behaviours. This is a vitally important issue for understanding the psychological processes that underlie both adaptive (e.g., searching for food) and destructive (e.g. drug-seeking) behaviours.

# Funding

This research was supported by an Australian Government Research Training Program Scholarship.

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# Table 1

*Experimental design of Quail et al. (2017)*

|  |  |  |
| --- | --- | --- |
| Instrumental training | Pavlovian training | Transfer test |
| R1 – O1  R2 – O2 | S1 – O1  S2 – O2  S3 – O3  S4 – No reward | S1: R1 vs R2?  S2: R1 vs R2?  S3: R1 vs R2?  S4: R1 vs R2? |

*Note*: R1 and R2 denote instrumental responses, S1-S4 denote Pavlovian stimuli, and O1-O3 denote rewarding outcomes.

# Table 2

*Experimental design of Hardy et al. (2017)*

|  |  |  |
| --- | --- | --- |
| Biconditional training | Transfer test | |
| SD1: R1-O1, R2-O2  SD2: R1-O2, R2-O1 | SD1 + S0: R1 vs R2?  SD1 + S1: R1 vs R2?  SD1 + S2: R1 vs R2? | SD2 + S0: R1 vs R2?  SD2 + S1: R1 vs R2?  SD2 + S2: R1 vs R2? |

*Note*: SD1 and SD2 denote discriminative stimuli, R1 and R2 denote instrumental responses and O1 and O2 denote rewarding outcomes. S0 represents a neutral stimulus, and S1 and S2 represent pictorial stimuli that are associated with the outcomes O1 and O2, respectively.

# **Table** 3

*Experimental design of Rescorla (1994b, Experiment 3)*

|  |  |  |  |
| --- | --- | --- | --- |
| Discriminative training | Instrumental training | Outcome devaluation | Transfer test |
| SD1: Rc – O1, O2  SD2: Rc – O3, O4 | R1 – O1, O3  R2 – O2, O4 | O1+, O4+  O2-, O3- | SD1: R1 vs R2?  SD2: R1 vs R2? |

*Note*: SD1 and SD2 denote discriminative stimuli, Rc, R1 and R2 denote instrumental responses, and O1-O4 denote rewarding outcomes. Plus (+) signs represent valued outcomes; minus (-) signs represent devalued outcomes.

1. The desire criterion in an essential component to most associative learning theorists’ definition of goal-directed control. We do acknowledge, however, that the notion of outcome value is complex and potentially involves multiple components (e.g., Hommel & Wiers, 2017). In particular, one might desire an outcome even following devaluation because it maintains value along other dimensions. [↑](#footnote-ref-1)