Implementations of Sign- and Goal-Tracking Behavior in Humans: A Scoping Review

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Abstract

Animal research has identified two major phenotypes in the tendency to attribute incentive salience to a reward-associated cue. Individuals called “sign-trackers” (STs) preferentially approach the cue, assigning both predictive and incentive values to it. In contrast, individuals called “goal-trackers” (GTs) preferentially approach the location of the upcoming reward, assigning only a predictive value to the cue. The ST/GT model has been shown to be relevant to understand addiction vulnerability and other pathological behaviors in animals. Therefore, recent studies tried to implement this animal model in the human population. This scoping review aims to identify and map evidence of human sign- and goal-tracking. Studies that explicitly measured human sign- and goal-tracking or related phenomena (e.g., attentional bias induced by reward-related cues), using paradigms in line with the animal model, were eligible for this review. We searched for published, unpublished and grey literature (PhD theses, posters, conference papers) through the following databases: MEDLINE, Scopus, PsycINFO, Embase, OSF, and Google Scholar. The JBI scoping review methodology was adopted. Screening and extraction were carried out by three reviewers, in pairs. A total of 48 studies were identified. These studies used various experimental paradigms and used the term “sign-tracking” inconsistently, sometimes implicitly or not at all. We conclude that the literature on human sign-tracking is very heterogeneous on many levels. Overall, evidence supports the existence of sign- and goal-tracking behaviors in humans, although further validated research is crucially needed.

Keywords: incentive salience, Pavlovian conditioned approach, animal model, eye-tracking, addiction, attention, motivation

Implementations of Sign- and Goal-Tracking Behavior in Humans: A Scoping Review

Individual differences in the propensity to attribute incentive salience to reward-predictive cues are relevant for the identification of risk profiles in several psychological disorders (Flagel et al., 2010). They may constitute a translational and transdiagnostic model for the etiology and maintenance of a variety of compulsive reward-seeking behaviors (Morrow et al., 2011; Pool & Sander, 2019; Saunders & Robinson, 2013). Indeed, over the past two decades, animal research has demonstrated that individuals with a higher sensitivity to reward cues are more vulnerable to these cues when related to disorders such as substance use disorders (SUDs) (Hellberg et al., 2019; Robinson et al., 2014; Robinson & Flagel, 2009; Saunders & Robinson, 2011).

In animal research, these effects were identified by means of the so-called “autoshaping” procedure, in which the brief presentation of a localizable discrete cue acting as a conditioned stimulus (CS) is predictive of the delivery of a food reward (US, unconditioned stimulus) immediately after its termination. Although no action is required to obtain the food reward, some individuals approach and interact with the CS (Brown & Jenkins, 1968). Those individuals are called *sign-trackers* (STs), because the predictive cue has become a “motivational magnet” following repeated association with the food reward (Anselme & Robinson, 2020; Berridge, 2007; Robinson & Flagel, 2009). Other individuals, called *goal-trackers* (GTs), only assign a predictive value to the CS; they are not motivationally attracted by the cue, and, during its presentation, they move directly toward the location where the reward is to be delivered. Finally, a portion of individuals are ambivalent, alternating between both types of behaviors (Flagel et al., 2008; Meyer et al., 2012). This variation in the topography of the conditioned response is not a matter of differences in the strength of Pavlovian learning, as both STs and GTs learn the CS-Food association. It rather reflects differences in the propensity to attribute incentive salience to discrete localizable CS (Flagel et al., 2009; Meyer et al., 2012; Robinson & Flagel, 2009; Saunders & Robinson, 2013), leading to differentiated stable phenotypes. The two phenotypes might be associated with different computational strategies, typically referred to as model-free for STs and model-based for GTs (Huys et al., 2014; Lesaint et al., 2014; Moin Afshar et al., 2023; Schad et al., 2020; Wuensch et al., 2021). Briefly, model-based learning means that the individual is using an explicit cognitive model to produce goal-oriented behaviors, while model-free learning means that the individual merely reacts to stimuli, based on statistical regularities or associations, and do not implement any cognitive model. This dissociation may therefore imply that GTs approach the reward location due to the previous learning that a reward will be available there (goal-directed), and STs approach and interact with the CS due to its incentive value (e.g., Pellón et al., 2018; Strand et al., 2022).

As outlined above, the propensity to sign-track may predispose individuals to approach and pay attention to cues repeatedly associated with reward. The Incentive Sensitization Theory of Addiction (Robinson & Berridge, 1993) relies on the evidence that exposure to highly rewarding substances, such as drugs of abuse, induces excessive attraction for their associated cues through permanent sensitization of dopamine neurons in the brain. So, there is a continuum between the incentive salience of a mere food cue (e.g., odor) and incentive sensitization, leading to various pathological behaviors such as overeating and craving—defined as “a strong desire or compulsion to take the substance" (World Health Organization, 1992). Incentive sensitization is a source of attentional biases, that is, implicit changes in attentional resource allocation and approach behaviors toward those cues (Field & Cox, 2008).

A growing body of literature has shown that the ST phenotype is associated with a higher vulnerability to drug addiction (Anselme & Robinson, 2020; Saunders & Robinson, 2011). Indeed, ST rats self-administer addictive substances more frequently and are more prone to relapse (Saunders & Robinson, 2011; Tomie et al., 2008). Compared to GT rats, they have also been shown to display other behavioral characteristics linked to pathological behaviors in humans, such as greater impulsivity (Meyer & Tripi, 2018), less top-down control (Paolone et al., 2013), and greater novelty-seeking (Beckmann et al., 2011). Given the predominance of the ST/GT model in the animal literature in the explanation of SUDs and other pathological behaviors (such as ADHD, inhibitory control, maladaptive eating behaviors, etc.), recent studies tried to implement this animal model in the human population.

For several years, researchers have attempted to find appropriate experimental paradigms to implement a human equivalent of sign-tracking behavior such as observed in rats and other species (for reviews see Anselme & Robinson, 2020; Colaizzi et al., 2020), a behavior whose relevance to human addiction is well known (Tomie et al., 2008). One major problem with human experimental settings, is that direct measures of behavioral approach (such as the time latency before physical contact or the number of lever presses by a rat) are not easily implemented, perhaps in part because human adults have internalized social rules of not touching what does not belong to them. As a direct consequence, a great majority of researchers have created paradigms in which approach is inferred from proximal measures (Saunders & Robinson, 2013), in particular visual attention allocated to a CS. This perspective sounds legitimate in the sense that sign-tracking is akin to the “attentional biases” observed, for instance, in response to drug cues compared to neutral cues in humans (Anselme & Robinson, 2020; Field & Cox, 2008).

To date, most attempts to measure human sign-tracking behavior were carried out through computerized tasks based on reaction time (Albertella, Le Pelley, et al., 2019; Albertella, Watson, et al., 2019; Liu et al., 2021; Watson, Pearson, Most, et al., 2019), sometimes coupled with an eye-tracking device (Garofalo & di Pellegrino, 2015; Schad et al., 2020). However, experimental paradigms that measure actual approach behaviors are also increasingly emerging (Colaizzi et al., 2023; Cope et al., 2019). Another procedure sometimes used in the ST/GT literature is the “Pavlovian-to-Instrumental Transfer” (PIT) task. The principle behind PIT is to induce a cue-reward association through Pavlovian conditioning to alter instrumental responses to the cue (Cartoni et al., 2016; for a recent review of this concept, see Garbusow et al., 2022). In altering the motivational influence of the reward predictive cue, PIT has much in common with sign-tracking (Garbusow et al., 2014). Indeed, individual differences in human PIT have been found to relate to sign- and goal-tracking behavior (Garofalo & di Pellegrino, 2015). The PIT effect has also previously been used to quantify incentive salience attribution (Sebold et al., 2021; Wassum et al., 2013). However, the PIT and the ST/GT paradigms also differ in many respects. In the PIT procedure, the propensity to attribute incentive salience to the CS is not directly tested. What is tested is the ability of the CS to alter the instrumental response for the reward. The standard PIT procedure cannot therefore easily identify ST/GT phenotypes. In the context of sign-tracking studies, only the Pavlovian phase of the PIT procedure may characterize behavioral phenotypes relating to sign- and goal-tracking.

The literature on human sign- and goal-tracking encompasses diverse experimental paradigms, including computerized and real-life tasks. A crucial point for the human study of sign- and goal-tracking is to use a definition of sign-tracking behavior as close as possible to that found in the animal literature. Indeed, inconsistencies and heterogeneity in the experimental results sometimes originate in differences in the interpretation of the phenomenon. For example, autoshaping denotes an experimental procedure and sign-tracking a behavior, but both terms are sometimes used as if they were synonyms and hence used interchangeably (Kearns & Gomez-Serrano, 2010; Pithers, 1982; Tomie & Morrow, 2018). In another vein, behaviors akin to sign- and goal-tracking in human participants have also sometimes been defined in very vague ways, such as “abnormal responses to reward cues” (Wardle et al., 2018) and “markers of impulsivity and attentional problems focusing on individual differences” (Serrano-Barroso et al., 2022).

While many attempts to transpose the animal ST/GT model in humans were published in the last decade, there has so far been no review summarizing the existing experimental paradigms. Gathering the relevant literature is made difficult by significant methodological deviations from the original ST/GT animal paradigm in some studies. Other studies investigate this phenomenon more closely, but without any reference to “sign-tracking” and/or “goal tacking”. Given the broad range of literature to be considered in the present review, precise inclusion criteria had to be defined. For instance, studies investigating attentional capture in relation to rewards were included because of their relevance for human sign-tracking behavior, whereas studies investigating attentional biases (i.e., the automatic capture of attention by stimuli naturally associated with rewards such as drugs of abuse or fast-food) were not included. Although attentional biases are clearly related to sign-tracking behavior, the inclusion of such studies would be far beyond the scope of the present review.

A preliminary search was conducted on Medline (OVID), PsycInfo (OVID), and the OSF platform. No planned or published systematic or scoping reviews on human analogs of sign- and goal-tracking behaviors were identified. A systematic review project was published on OSF (McGinley, 2020), but only focuses on the PIT paradigm. Colaizzi et al. (2020), as well as Anselme and Robinson (2020), have reviewed and discussed the neurobiological and behavioral aspects of sign-tracking in animals while describing recent attempts to translate animal research in humans. Colaizzi and colleagues concluded that “while it appears that sign- and goal-tracking behaviors are measurable in humans, it is yet unknown the optimal methodologies for measuring these behaviors and whether these tendencies are temporary states, consistent life-long traits, or if they develop over time” (p. 91). Anselme and Robinson stated that “in humans, sign-tracking can be likened to a form of attentional bias” (p. 9), and that “attentional bias in humans and sign-tracking in animals may therefore likely underlie similar phenotypes, both primarily modulated by dopaminergic activity, and could provide a strong translational bridge for addiction and gambling research” (p. 9). To the best of our knowledge, however, no systematic description of the domain including recommendations for future research has yet been provided. Given the diversity in the ways of implementing the ST/GT model in humans (Colaizzi et al., 2020) and the lack of consensus on the method to be used, the present scoping review aims to identify and map what has been done on this topic. A synthesis of this literature is crucial for future research, as it represents a first step towards a consensus on the human analog of a widely validated paradigm in animal research, potentially relevant for the study of vulnerability factors for several pathological behaviors. The research question of the current review was “What is known about sign-tracking/goal-tracking in humans? And what methods have been used to implement and measure a human equivalent of sign- and goal-tracking behaviors in animals?”.

Methods

This review was conducted in accordance with the JBI methodology for scoping reviews (Peters et al., 2020) and was reported according to the PRISMA Extension for Scoping Reviews (Tricco et al., 2018).

Inclusion Criteria

Participants

This scoping review considered studies that included human subjects, regardless of gender, age, health status, or ethnicity.

Concept

This scoping review considered studies that implemented and measured sign-tracking and/or goal-tracking behavior in humans. Because there is no unequivocal definition of the human analog of this model, this review included studies that:

- Explicitly mentioned implementing or measuring sign-tracking/goal-tracking behavior in humans, regardless of the method used.
- Did not explicitly mention human sign- or goal-tracking, but referred to closely related concepts/methods such as:
    - the "tendency to attribute incentive salience to reward stimuli", or “the vulnerability/susceptibility to the influence of Pavlovian cues” in humans,

with a measure that is equivalent or very close to sign- and goal-tracking behavior in animals,

- human PIT, and included a measure that is equivalent or very close to sign- and goal-tracking behavior in animals,
- “human autoshaping”, with a measure that is equivalent or very close to sign- and goal-tracking behavior in animals,
- “reward-related attentional capture” in human subjects, with a measure that is equivalent or very close to sign- and goal-tracking behavior in animals.

In order to consider only experimental paradigms that were “equivalent or very close to” to the animal ST/GT model, we needed to establish more specific exclusion criteria. The exclusion procedure was therefore based on 5 sub-criteria, which were used during the whole process. Studies that did not explicitly state implementing or measuring human sign- and goal-tracking were excluded when:

- The CS-US association was not created in the laboratory (within the experimental setup) but occurred in real-life settings (e.g., a well-known logo such as “McDonald’s yellow M”). This excluded most attentional bias studies, which were out of the scope of the present review.
- There was no opposition between the attractiveness of the CS and of the reward delivery location (this excluded, for example, studies in which the response to the CS was recorded under extinction, a scenario unrelated to the Pavlovian autoshaping paradigm).
- Reward delivery required an instrumental response (i.e., the CS-US association was not purely Pavlovian, as it is in the animal model).
- The experiment did not involve a positive outcome (i.e., absence of reward during the task or learning based on aversive conditioning).

- The experiment did not involve a measure of CS attractiveness (this excluded experiments only based on instrumental measures such as invigoration of response rates, pure reaction time measures or physiological measures, as these strongly deviate from the initial animal model).

In brief, this review included: (1) studies that clearly state that they investigate human sign- or goal-tracking, regardless of the methods used; (2) studies that claim to investigate human sign- or goal-tracking (or draw an explicit parallel with it) even though they meet some of the exclusion criteria; and (3) studies that do not explicitly claim to investigate human sign- or goal-tracking but used similar methods described above, with the additional condition that they do not meet one of the exclusion criteria.

Context

This review considered all contexts.

Types of Sources

In this scoping review, we included published or unpublished experimental studies written in English, as well as grey literature (except Undergraduate and Master theses).

Search Strategy

The search strategy aimed to find published, unpublished, and grey literature relevant to the review question. First, an initial limited exploratory search was conducted to help identify relevant search terms. Next, a complete search using all identified keywords and index terms was undertaken on April 26, 2023. The consulted resources were Medline (OVID), PsycInfo (OVID), Embase (Elsevier) and Scopus (Elsevier) (Appendix 1). Subsequently, the reference lists of the included studies and of the relevant reviews found during the search process, were hand searched for additional studies. Finally, citing literature (identified through Google Scholar’s “cited X times”) of the selected studies was scanned for relevance and possibly included. A complementary literature search was completed on November 6, 2023, through Google Scholar and OSF platform. Citation searching of included sources was performed on November 30, 2023. For any posters or congress papers identified, a search by author was performed to seek for a published version of the studies they present (this was not planned in the registered protocol).

The research was not restricted to a given period, because the first human sign-tracking studies date back to the 1980s.

Study Selection

After the search was completed, all records were uploaded to the Covidence systematic review software (Covidence systematic review software, Veritas Health Innovation, Melbourne, Australia), and duplicates were removed. Three reviewers, in pairs, independently screened the title and abstract of studies, and excluded studies that did not met the inclusion criteria. One reviewer screened all references (MH) and two reviewers, each screened half of the references (PA & EQ). The full-text studies were retrieved and uploaded to Covidence. The selected studies were then assessed independently by three reviewers (same procedure as mentioned above) to determine if they met the predefined inclusion criteria. Any disagreement was resolved by consensus or through discussion with the third reviewer. Quality appraisal of the selected studies was not conducted since the standard procedure and aim of scoping reviews is to provide an overview of the literature (Peters et al., 2020).

Data Extraction

Data were extracted from the included sources by three independent reviewers (same as mentioned above) using a data extraction tool developed by the authors (see Appendix 2) and refined during the process, following the JBI scoping review methodology (Peters et al., 2020). Any disagreements that arose between reviewers were resolved through discussion or with the third reviewer. When necessary, the authors of the selected studies were contacted to request missing or additional data. In case no response was received within the next two weeks, only the available data were extracted (this was not mentioned in the registration but had to be decided during the process for scheduling reasons).

Data Analysis and Presentation

Results are presented graphically or with tables when useful. The accompanying narrative further describes the literature. The findings of the review are presented in five sections, organized according to the experimental paradigms that were identified, and one additional section.

Transparency and Openness

We adhered to the PRISMA 2020 guidelines for systematic reviews (Page et al., 2021). There is no data or code available since this is a theoretical review. Graphical presentations were created using R, version 4.3.3 (R Core Team, 2024). This review project was preregistered on OSF, at https://osf.io/utfcq/. Two amendments were made after protocol registration and are already mentioned above. They concern (1) an additional search by author name, for each identified poster/congress paper, and (2) the definition of five precise exclusion criteria, allowing us to consider only experimental paradigms that were “equivalent or very close to” to the animal ST/GT model.

Results

Study Inclusion

A total of 2754 references were identified and uploaded to Covidence for screening. Of these, 1602 were duplicates. At the title and abstract phase, 1152 studies were screened, with 925 classified as irrelevant. Five citations were not available as full text, neither in open access, nor through our libraries or after contacting the authors. There were 222 full-text studies assessed for eligibility through full-text screening, and 178 were excluded (see Appendix 3 for PRISMA flowchart, Page et al., 2021).

The complementary search resulted in the inclusion of 11 additional reports Three articles for which we already identified the preprints were published in January 2024 and were thus merged with their preprint (Cherkasova et al., 2024; Dinu et al., 2024; Watson et al., 2024). In total, 46 studies (from 58 reports) were included in the review.

Characteristics of the Included Studies

The characteristics of the included studies are presented in Table 1 (Appendix 4). Studies were published across the date range 1974 to 2024, showing an early interest for this topic 50 years ago and a growing interest since 2015 (see figure 1). Thirty-nine studies were reported in journal articles, 3 in PhD theses, 3 in posters or conference abstracts, and 1 in a preprint. One PhD dissertation was subdivided into 3 parts, because 3 very different paradigms were implemented in the research program (Colom, 2023).

Review Findings

Studies implementing human sign-tracking (or closely related behaviors) can be classified into four major categories of experimental paradigms: (1) Physical Pavlovian Conditioned Approach (PCA) tasks or similar methods (N=8), (2) Virtual Pavlovian Conditioned Approach tasks either embedded in a PIT task (N=5) or alone (N=5), (3) Value-modulated attentional capture (VMAC) tasks either with (N=13) or without (N=9) an eye-tracking measure, and (4) “Alternative” tasks (not included in the previous categories, i.e., “game-like tasks”, “neuroimaging”, “real-life & electrophysiological measures”, and “unclassified tasks”, N =8). Figure 2 shows the breakdown of studies in four these categories.

Studies were grouped according to these four major categories, which are described below in section 3.3.1. For each category, we summarized the task characteristics, type of participants studied and main findings relevant for the present topic, in a narrative way. The first two categories were closer to the animal ST/GT paradigm and were therefore described in more depth. Detailed information about studies (sample description, etc.) is summarized in Table 1 (Appendix 4). For studies explicitly implementing or measuring sign- or goal-tracking behavior in humans that were included on that basis, note that some of them met our exclusion criteria and are reported in Table 2 (Appendix 4).

Two additional characteristics of major importance were identified and summarized for each category of paradigms in a separate section (3.3.5): (1) the presence of a ST and GT (and INT) categorization of participants in the study, and (2) the type of rewards used in the different experimental paradigms.

Physical Pavlovian Conditioned Approach Tasks

Few research teams have implemented actual PCA tasks, where the participants can physically interact with a CS (often a lever) and a US (e.g., coin or food dispenser) (n=8). In these tasks, approach behavior and attractiveness of the CS are measured through actual contacts with both stimuli (sign vs goal), like in animal studies.

Some of these PCA studies (n=4) were published in the 70’s and 80’s, before the terms “sign-tracking” and “goal-tracking” became popular. Their goal was to investigate either *autoshaping behaviors* in humans (Anderson et al., 1981; Pithers, 1985; Wilcove & Miller, 1974), or *superstitious behavior acquisition* in children (Wagner & Morris, 1987). While two of these studies were conducted on children (Anderson et al., 1981; Wagner & Morris, 1987), the two others were conducted on student participants. As precursors of the contemporary study of human sign-tracking, these studies implemented experimental devices, including movable levers (and lights) and coin dispensers, with which the participants could interact. Both studies with children used a device designed as a “clown box” that delivered rewards through its “mouth”. The rewards used in these experiments were mainly coins, except in Wagner and Morris (1987), which implemented a marble delivery system. Children could exchange collected marbles for preselected toys at the end of the study. Broadly speaking, these studies found no clear evidence of CS-oriented (sign-tracking-like) behaviors in humans compared to studies with non-human animals (Anderson et al., 1981; Wagner & Morris, 1987; Wilcove & Miller, 1974), except for Pithers (1985) who reported conditioned responses in participants when the CS and the US were paired, but not when they were unpaired, results in line with previous animal findings. Despite their striking methodological similarities with the animal autoshaping procedure, these studies had several major limitations with respect to the ST/GT framework. Many of them provided a descriptive rather than quantitative assessment of CS-oriented behavior (Anderson et al., 1981; Wagner & Morris, 1987; Wilcove & Miller, 1974). In other words, they mainly assessed the dominant behaviors occurring following the presentation of a reward-associated cue, without reporting how children/students behaved relative to the cue and the reward location. As a result, the participants could not be classified according to the degree of CS attractiveness using a ST/GT categorization.

After more than two decades of absence in the scientific literature, physical PCA tasks recently benefited from renewed interest with the publication of four studies explicitly investigating human sign-tracking behavior. Two of these sources originate from PhD theses (one type of publications from the grey literature) and developed new and innovative ways to measure sign- and goal-tracking in humans (Colom, 2023, Chapter 9; Joyner, 2019). Again, half of the studies were conducted on children/pre-adolescents (Colaizzi et al., 2023; Joyner, 2019), while the others were conducted on an institutional sample (Colom, Chapter 9), or in emerging adults from a research volunteer database (Cope et al., 2023). The experimental devices of these studies mainly consisted of extendable levers and reward magazines, except for Colom (2023, Chapter 9), where pressable buttons were used as CS. Rewards ranged from food (Joyner (2019) to colorful plastic marbles or tokens, exchangeable for either preselected food items (Colom, 2023, Chapter 9) or money (Cope et al., 2023), or prizes or money (Colaizzi et al., 2023). Participants were mostly classified as STs and GTs on the basis of a complex index score opposing behaviors towards the CS versus the reward location, derived from the animal literature (see Meyer et al., 2012). The distribution of this score is then typically split in three, leading to three distinct groups, with the “intermediate group” being sometimes removed from the analyses (Colom, 2023, Chapter 9). Cope et al. (2023) however identified ST, GT, and intermediate groups using a latent profile analysis on measures of lever presses and gazes. While all four of these studies intended to categorize participants into ST/GT groups, only two of them did identify distinct behavioral profiles in line with sign- and goal-tracking (Colom, 2023, Chapter 9; Cope et al., 2023). Since Joyer's (2019) and Colaizzi and colleagues' (2023) participants showed very limited GT behavior, they rather created ST and non-ST groups. Overall, physical PCA studies were able to identify ST and GT phenotypes (or at least non-STs, including intermediates) in humans. Based on predictions from animal studies, these ST and GT phenotypes were tested for their differences on impulsivity-related variables, but mixed results were obtained. Two studies found an association between impulsivity and sign-tracking (Colaizzi et al., 2023; Cope et al., 2023), whereas the other two reported negative results (Colom, 2023; Joyner, 2019).

Virtual Pavlovian Conditioned Approach Tasks

The virtual versions of the physical PCA task are more common and remain close to the ST/GT animal model. They have been used alone (N=5) (Colom, 2023, Chapter 7 & 8; Dinu et al., 2024; Doran, 2016; Ottaviani et al., 2023) or in the context of PIT paradigms (N=5) (Cherkasova et al., 2024; Garofalo & di Pellegrino, 2015; Lehner et al., 2017; Schad et al., 2020, 2023). These tasks consist in associating a visual CS (often a fractal picture) with the delivery of a reward on a computer screen. Briefly, the CS appears at a specific location on the screen for a short amount of time (3 to 5s), followed by the reward on the opposite side of the screen. The task of the participants is usually to collect the reward by pressing a key on a computer keyboard. With one exception (Colom, 2023, Chapter 8), these studies used an eye-tracking device to quantify the amount of gaze fixation on the CS versus the location of reward delivery. Colom (2023, Chapter 8) proposed a novel "virtual room-based Pavlovian environment" where participants were allowed to interact with pulling levers and light buttons, in a procedure similar to the ST/GT animal paradigm. The task was therefore based on virtual approach behaviors rather than attentional capture by the CS.

STs or GTs are usually identified based on a contrast between amount of gaze fixation on the CS versus the location of reward delivery (Cherkasova et al., 2024). These studies have used median or tertiary split to discriminate ST/GT phenotypes, sometimes excluding intermediates from the analyses (Colom, 2023; Schad et al., 2020; Dinu et al., 2024 used both methods). Schad and colleagues (2020) used a different approach to create ST and GT groups. They computed the influence of CS value on gaze index during the last second of CS presentation per participant. STs and GTs were then defined as those with the most positive and the most negative regression coefficients, respectively. These authors also proposed an alternative way to define STs and GTs through computational modelling.

Most of the studies using a virtual PCA task have been conducted on healthy adult volunteers from the general population (Doran, 2016; Cherkasova et al., 2024; Colom, 2023, Chapter 8; Garofalo & di Pellegrino, 2015; Ottaviani et al., 2023). Others have been conducted on young males (Schad et al., 2020), or recently detoxified alcohol-dependent patients in comparison to healthy controls (Schad et al., 2023). An institutional sample has also been studied (Colom, 2023, Chapter 7). Since Lehner et al. (2017) investigated the relationship between sensitivity to rewards and reward-predicting cues and obesity, their sample was constituted of adult volunteers recruited through announcements of the Swiss Adiposity foundation in local clinics, self-help groups, plus-size clothing stores, and the university website. The most common kind of reward used in these studies was money, symbolized through coin or bank note pictures in the experimental task (Doran, 2016; Cherkasova et al., 2024; Garofalo & di Pellegrino, 2015; Ottaviani et al., 2023; Schad et al., 2020). Virtual money (coin or banknote pictures) that is not converted to actual money at the end of the experiment, has also been used (Colom, 2023, Chapters 8 and 9; Dinu et al., 2024). In line with their study's objective, Lehner et al., (2017) materialized rewards through images of sweet or salty snacks, that were accumulated throughout the task and obtained at the end of the experiment. While one study showed a positive association between sign-tracking behavior and impulsivity (Garofalo & di Pellegrino, 2015), no association with impulsivity or substance use was found in other studies (Colom, 2023, Chapter 8; Doran, 2016). On a neuronal level using fMRI, Ottaviani et al. (2023) reported a subcortical control in sign-tracking behavior and a more cortical influence in goal-tracking behavior, while Schad et al. (2020) showed a double dissociation between model-free and model-based learning in human STs vs GTs, with STs showing a neural reward prediction error signal that was not detectable in GTs. Moreover, GTs showed lower PIT effects, which might reflect distinct motivational properties of the CS. The same research team investigated human sign-tracking again through a PIT task coupled with an eye-tracking and fMRI imaging, in detoxified alcohol-dependent patients compared to matched healthy controls (Schad et al., 2023). They replicated the distinction between STs and GTs, in relation to model-free and model-based learning, in the patient group, but not in the control group. Contrary to their expectations, they did not find an increase of sign-tracking in the patient group and found that GTs were more prone to relapse. Three other studies also did not confirm their hypotheses. Dinu et al. (2024) and Cherkasova et al. (2024) found no relationship between ADHD and sign-tracking and found goal-tracking to be linked to greater risk-promoting effects of cues, respectively. In one study of the PhD thesis, Colom (2023, Chapter 7) failed to identify consistent ST/GT profiles using a computerized task with eye-tracking. Indeed, participant’s behaviors were more related to preexistent attentional biases rather than to individual differences in incentive salience attribution to the reward predicting cues. Regarding the association with obesity, Lehner et al. (2017) found that fixation style (i.e., sign- or goal-tracking tendencies) had a complex interaction with body weight, notably overweight participants had a significant bias toward the reward location.

VMAC Tasks

A parallel has sometimes been established between sign-tracking in animals and *value modulated attentional capture* or VMAC (Albertella, Watson, et al., 2019; Albertella, Le Pelley, et al., 2020; Byrom & Murphy, 2018; Colaizzi et al., 2020; Le Pelley et al., 2015, 2024; Pearce et al., 2022; Wiers et al., 2021), sometimes also called “value-driven attentional capture” (Pearce et al., 2022) in humans. This experimental task, initially developed by Le Pelley et al. (2015), measures the extent to which a signal for reward comes to exert control over behavior through attentional bias (Watson, Pearson, Most, et al., 2019). In the VMAC task, participants are requested to respond to a target stimulus as quickly as possible (e.g., detecting a diamond shape within circles and reporting the orientation of the line inside the target shape), while another visual cue (color distractor) signals the magnitude of a reward opportunity (high vs. low reward) (Figure 3).

Typically, distractor cues are of two colors (e.g., red and blue), each predicting a specific reward magnitude (e.g., red for high reward, blue for low reward). To get the reward, participants must respond as quickly as possible to the target, and too slow responses lead to reward omission. In that respect, several versions of the VMAC task were used. Sometimes, the procedure is designed to punish gazes to the reward-associated distractor through reward-omission (Albertella et al., 2017; Pearson et al., 2015, 2016, 2020; Pearson & Le Pelley, 2020, 2021; Watson, Pearson, Chow, et al., 2019; Watson, Pearson, & Le Pelley, 2020; Watson et al., 2021, 2022), and sometimes the reward magnitude is dependent on response speed (Albertella, Le Pelley, et al., 2019; Albertella, Watson, et al., 2019; Albertella, Chamberlain, et al., 2020; Albertella, Le Pelley, et al., 2020; Albertella et al., 2021; Duckworth et al., 2022; Liu et al., 2021; Watson, Pearson, Most, et al., 2019). Therefore, the most profitable behavior for the participant is to ignore the distractor and only attend to the target stimulus. In spite of the cost of such behavior, participants still tend to look at the distractor and this effect is heightened for distractors predicting higher rewards (Le Pelley et al., 2015; Pearson et al., 2015). This behavior is assumed to be underpinned by the automatic attribution of incentive salience to the reward predicting cue, which makes it similar to sign-tracking behaviors in animals (Albertella, Le Pelley, et al., 2019; Colaizzi et al., 2023; Pearce et al., 2022). The VMAC task is sometimes coupled with an eye-tracking device, allowing the quantification of the attentional capture by the reward predicting cue. This component is therefore particularly relevant for the study of sign-tracking behavior in humans. Below, we distinguish VMAC studies with and without eye-tracking. The most commonly used reward in these tasks consists in points, which can be accumulated and converted into money.

VMAC Without Eye-Tracking. Among the VMAC studies without eye-tracking, some of them explicitly draw a parallel with the ST/GT paradigm (Duckworth et al., 2022; Liu et al., 2021; Watson et al., 2023), while others do not despite using a very similar procedure and were therefore also included in the present scoping review (Albertella, Chamberlain, et al., 2020; Albertella et al., 2021; Albertella, Le Pelley, et al., 2019, 2020; Albertella, Watson, et al., 2019; Watson, Pearson, Most, et al., 2019).

While most of these studies were conducted on adults from the general population (Albertella, Chamberlain, et al., 2020; Albertella et al., 2021; Albertella, Le Pelley, et al., 2019, 2020; Duckworth et al., 2022; Liu et al., 2021) or students (Albertella, Watson, et al., 2019; Watson, Pearson, Most, et al., 2019), one recent study recruited individuals seeking treatment for problematic alcohol use (Watson et al., 2024).

Duckworth et al. (2022) investigated the neural correlates of sign-tracking. According to their results, "sign-tracking is associated with activation of the 'attention and salience network' in response to reward cues but not reward feedback". Liu et al. (2021) investigated the association between sign-tracking and alcohol drinking motives in relation to problematic drinking. Although they found no difference in alcohol use between the participants classified as ST and GT, they showed that the ST/GT phenotype was a moderator of the relationship between drinking motives and alcohol consumption. However, there was no direct relationship between sign-tracking and alcohol use.

In a more clinical perspective, Watson et al. (2024) studied human sign-tracking in relation to problematic alcohol use and relapse. Results showed that a VMAC score indicative of sign-tracking positively correlated with the severity of alcohol use, obsessive thoughts about alcohol use and compulsive drinking behavior. Moreover, sign-tracking predicted alcohol relapse at three months.

Several other studies with a very similar VMAC methodology also found a significant relationship between the VMAC scores and compulsive or alcohol drinking behaviors, although they did not express their results in terms of sign-tracking. Albertella and colleagues (Albertella, Chamberlain, et al., 2020; Albertella, Le Pelley, et al., 2019, 2020; Albertella, Watson, et al., 2019) showed that reward related attentional capture is significantly related to compulsivity and risky alcohol use. They also showed that people with greater reward related attentional capture (i.e., STs) were more likely to fail a 1-month abstinence challenge (dry January) (Albertella et al., 2021). Finally, Watson, Pearson, Most, et al. (2019) draw a parallel between the VMAC task and the ST/GT paradigm. They showed that participants were significantly slower on trials with a distractor announcing a high reward availability (vs. a low reward availability), and that this effect persisted during an unrewarded extinction phase.

VMAC With Eye-Tracking. Although the VMAC studies coupled with an eye-tracking device (N= 13) do not explicitly refer to the ST/GT paradigm, the addition of a measure of attentional capture by the reward-associated cue makes the results of such studies quite relevant for the investigation of human sign-tracking behavior. All of these studies were conducted on student samples (Albertella et al., 2017; Le Pelley et al., 2015, 2019; Pearson et al., 2015, 2016, 2020; Pearson & Le Pelley, 2020, 2021; Watson, Pearson, Chow, et al., 2019; Watson, Pearson, & Le Pelley, 2020; Watson, Pearson, Theeuwes, et al., 2020; Watson et al., 2021, 2022).

Albertella et al. (2017) found a significant association between the VMAC effect and drug use, and this relationship was modulated by the level of cognitive control. Contrary to students with a high cognitive control, those with a low cognitive control showed a significant positive correlation between their VMAC scores and illicit drug use. Other authors used very similar procedures to study reward-related attentional capture (Le Pelley et al., 2015, 2019; Pearson et al., 2015, 2016, 2020; Pearson & Le Pelley, 2020, 2021; Watson, Pearson, Chow, et al., 2019; Watson, Pearson, & Le Pelley, 2020; Watson, Pearson, Theeuwes, et al., 2020; Watson et al., 2021, 2022). Overall, these studies consistently showed that participants developed an automatic counterproductive attentional bias for high reward signals, which persisted even when looking at the distractor caused reward omission (Le Pelley et al., 2015; Pearson et al., 2020; Watson, Pearson, Theeuwes, et al., 2020), when the reward was devaluated (Watson et al., 2022), when participants were explicitly told that looking at the distractor would lead to reward omission (Pearson et al., 2015), or when both distractor types (low and high reward) were presented simultaneously (Pearson et al., 2016). Moreover, this attentional bias was more pronounced for rapid eye saccades (Le Pelley et al., 2019) and was increased by a high memory load (Watson, Pearson, Chow, et al., 2019). Interestingly, this attentional bias also occurred with food rewards, and was reduced in individuals scoring higher on eating restraint (Watson et al., 2021). It was also shown to be reduced by an acute alcohol dose (Watson, Pearson, & Le Pelley, 2020). Pearson and Le Pelley (2020, 2021) concluded that the relationship between reward and attentional selection is complex in the sense that the automatic capture of attention by reward-associated cues may be attenuated when attending to the distractor leads to reward omission.

Alternative Tasks

Several other studies explicitly investigated human sign- and goal-tracking behaviors or were relevant for the topic but could not be classified in the previous major categories (N=8). They were classified as (1) “game-like tasks” (N=3), (2) “neuroimaging experiment” (N=2), “real-life assessment” (N=1), and “unclassified tasks” (N=2).

Designing game-like tasks to measure human sign- and goal-tracking could be an ingenious way to tackle the issue of ecological translation. Indeed, a videogame could be much more engaging for human participants than a mere piece of food collected after presentation of a touchable lever CS; humans have been playful beings (“*Homo ludens”*) since the dawn of time (Huizinga, 1998). Among the papers in this category, Serrano-Barroso et al. (2022) used a “pinky-piggy” videogame application with 4- to 5-year-old children, where two CS (money bag and a colorful pig) were associated with coins (US) appearing on the screen. In this task, a money bag and a grey pig were displayed on a screen. Four seconds later the bag began to shake, and the pig became colored, then coins appeared on the screen. The children had to touch the pig to accumulate virtual money. All touches on the screen were registered throughout the task but had no incidence on reward contingency. Touching the pig produced an oink sound, while touching the bag emitted a coin shaking sound. The authors indicate that the app was designed in reference to autoshaping, presented as “a classical experimental procedure in animal models” (p. 4). Although the task was very similar to the ST/GT paradigm, the results were not directly interpreted in reference to sign- and goal-tracking behaviors. Accordingly, participants were not categorized as STs or GTs. Instead, the authors used “high responders” (HR) vs “low responders” (LR) categories, based on their number of clicks (on the bag and the pig cues). Their categories were therefore homologous but not equivalent to ST/GT phenotypes. The main result was that high responders had lower scores on neurodevelopmental scales (for non-verbal development, spatial structuring, and visual perception), and showed a lower mean level of attention than low responders.

Two other studies by Nelson et al. (2019, 2022) used a game-like procedure coupled with an eye-tracking device to assess sign- and goal-tracking behaviors in university students and college-aged volunteers. In their videogame, participants had to learn to activate weapons to repel invading spaceships. Eye gazes toward a specific spaceship (the outcome or US) and toward a flashing light cue (CS) predicting this outcome were recorded throughout the task. The two aims of these studies were to assess visual searching for expected outcomes in humans during an associative-learning task (Nelson et al., 2019), which they define as goal-tracking, and to examine the effects of stimulus pre-exposure and conditioning on visual attention (Nelson et al., 2022). In the second study, participants were classified as STs or GTs according to their preference for the CS or the US. A ratio score was computed by dividing the number of gazes in the US zone by the total number of gazes on the last trial. Nelson et al. (2022) defined sign-trackers as “individuals preferring to look at the signal predicting the upcoming spaceship", and goal trackers, as "preferring to look for the appearance of the predicted ship, at the end of training". The results suggested that STs and GTs were differentially sensitive to the effects of pre-exposure to the CS and to context changes.

In a completely different vein, Versace et al. (2016) investigated human sign- and goal-tracking through brain responses to pictures in obese and lean adult individuals. The aim of their study was to dissociate two endophenotypes related to individual differences in the propensity to attribute incentive salience to food-related cues. Participants were exposed to food-related, pleasant, neutral, and unpleasant pictures while recording electroencephalogram. STs and GTs were categorized using a latent profile analysis based on their late positive potentials. STs were individuals with higher responses to food-related cues and lower responses to pleasant cues, contrary to GTs. Obese individuals were more often classified as STs than lean individuals. Members of the same research team also investigated how gut microbiome profiles varied between STs and GTs in obese and lean individuals. They reported preliminary findings in a poster (Schembre et al., 2016) suggesting that STs and GTs show varying gut microbiota, with STs having a more diverse microbiome compared to GTs.

To study sign- and goal-tracking behaviors in a more ecological way, Schettino et al. (2022) implemented an ecological momentary assessment and ambulatory peripheral autonomic monitoring. In their daily life, adult participants from the general population had to rate the attractiveness of several pre-selected (preferred) rewards and their naturally associated predictive cues. For instance, rewards and their predictive cues could be coffee and the noise of the coffee machine, respectively. At the same time, their electrocardiogram was recorded. The results indicate that, overall, participants rated cues and rewards as equally attractive. However, individuals with higher impulsive, obsessive-compulsive and addiction-prone tendencies rated the predictive cues as more attractive compared to the rewards themselves, and this pattern was also reflected in autonomic measures.

Salmeron (2020) investigated human sign- and goal-tracking in adults with and without substance use disorders. Participants had to watch a set of pictures (food, drug, positive, and neutral pictures) on a screen. They could push a button to extend the display duration of a picture, but no actual reward was granted to the participants during the task. A sign-tracking score was computed based on their responses to the pictures. Contrary to what the animal literature indicates, healthy controls showed more sign-tracking behavior than substance users. Moreover, sign-tracking correlated negatively with drug consumption in smokers and cocaine users.

Finally, Wardle et al. (2017, 2018) developed a new procedure devised to be a translational paradigm to measure human sign-tracking (2017). In their task, the favorite food reward of a participant was repeatedly paired with an initially neutral picture (CS). More specifically, healthy adult participants were seated in front of a computer screen wearing headphones, with a partition to their side. A rotating tray was in the partition, with one food tray on each side. A research assistant was seated on the other side, manually loading the food cup with the participants' selected food reward. Right after the CS picture was shown on the screen (6s), the assistant rotated the tray to deliver the reward. Participants were instructed to eat the snacks within the 25s after delivery (they were not allowed to keep it for later). Psychophysiological measures (electromyography, skin conductance, and heart rate) were also recorded during the task. After two conditioning sessions, several measures of appetitive responses to the CS were then performed (i.e., Rating Pictures Task, Chasing Pictures Task, and Dot-Probe Task). The results showed appetitive conditioned responses to the CS picture with some of the measures, especially the psychophysiological recordings, but no significant approach behavior or positive subjective ratings of the CS. Unexpectedly, the various appetitive measures for the CS picture did not strongly correlate with each other (Wardle et al., 2018). Attentional bias for the CS picture (as measured by a Dot-Probe task) was the only indicator of appetitive conditioning that significantly correlated with impulsivity.

Summary of Some Important Divergent Methodological Features of the Reviewed Studies

In addition to the methods used to measure sign- and goal-tracking behaviors in humans, two other aspects were found to be highly heterogeneous in the literature.

First, the various human paradigms greatly differ in their attempts to identify distinct ST and GT phenotypes. As already mentioned, in some of the human paradigms listed above, the “sign” (CS) and the “goal” (reward location) were insufficiently contrasted to allow for such classification of participants. Figure 4 shows the proportion of studies implementing a participant profile classification, for each category of paradigms described in section 5.3. Among physical PCA task studies, all contemporary ones have categorized participants into groups of STs/GTs/INTs (Colaizzi et al., 2023; Colom, 2023, Chapter 9; Cope et al., 2023; Joyner, 2019), whereas the oldest physical PCA studies did not. Virtual PCA task studies have all identified different groups of participants based on their sign-or goal-tracking behavior, although Lehner et al. (2017) did not use the terms STs/GTs, but rather categorized participants into two groups according to their predominant eye fixation on the CS or the reward location (“high eye index” vs “low eye index”). Except for two studies (Duckworth et al., 2022; Liu et al., 2021), VMAC paradigms did not typically lead to a ST/GT categorization, but rather considered a continuous score of biased attentional capture. As for the alternative tasks, only three studies used a ST/GT categorization (Nelson et al., 2022; Schembre et al., 2016; Versace et al., 2016).

The second major source of disparity between the reviewed studies is the type of reward used. Figure 5 shows the types of rewards used for each category of experimental paradigms identified in the present review (see also Table 1 (Appendix 4) for type of reward per study). While some studies used actual money as the reward (e.g., Anderson et al., 1981; Cherkasova et al., 2024; Garofalo & di Pellegrino, 2015), others used a points system, with points being converted into a financial reward at the end of the experiment (sometimes based on task performance, sometimes a fixed amount) (e.g., Cope et al., 2023; Duckworth et al., 2022; Pearson et al., 2016). Purely “virtual rewards”, such as coin pictures, points/medals accumulation along the task, have also been widely used (e.g., Albertella et al., 2021; Serrano-Barroso et al., 2023; Watson, Pearson, Most, et al. 2019). Several food items (or drinks) have also been used as rewards in studies measuring human sign-tracking, either directly delivered (Joyner, 2019; Lehner et al., 2017; Wardle et al., 2018) or exchanged for points accumulated during the experimental task (Watson et al., 2021,2022). Finally, several of the “alternative tasks” did not implement the opportunity to receive any rewards at all during the task (e.g., Versace et al., 2016; Salmeron, 2020).

Discussion

The purpose of this scoping review was to identify and map what has been done on sign- and goal-tracking in humans, and more specifically, identify what paradigms have been used to implement it. The reviewed studies were presented according to four major categories of experimental paradigms: physical PCA, virtual PCA, VMAC and alternative tasks.

The first attempts to test human “sign-tracking” under the term “autoshaping” date back to the 1970s (Anderson et al., 1981; Pithers, 1985; Wilcove & Miller, 1974). The thematic then seemed to be forgotten until the mid-2010’s, when it has made a significant come back in the scientific literature (see Figure 1). In recent years, a number of studies have tried different methods to develop a human analog of sign-tracking behavior.

As shown in the present review, there is a huge heterogeneity in the methodologies of the studies claiming to investigate sign- and goal-tracking behaviors in humans. Additionally, some studies investigate behavioral analogs of sign-tracking without reference to the ST/GT literature. Until now, there is no consensus on the best way to measure those behaviors in human participants. To bring some order in this diversity, we have classified the published studies into for major categories: physical PCA tasks, virtual PCA tasks, VMAC tasks, and alternative, non-classified tasks. Overall, physical PCA tasks show the greatest face validity by mimicking CS-triggered approach behavior measured in animals. Accordingly, the findings from these PCA studies are generally in line with the conclusions from the animal literature on sign-tracking. Although they could be considered a gold standard for the translation of the ST/GT model in humans, they require sophisticated materials and resources and may also lack sufficient ecological validity, especially in adult human participants. This is probably why half of these studies were conducted in children, who might be more prone to spontaneous interaction with colorful devices.

As approach behaviors are not easily recorded in humans, several authors developed proximal measures in virtual PCA tasks (e.g., Cherkasova et al., 2024; Colom, 2023; Dinu et al., 2024; Garofalo & di Pellegrino, 2015; Ottaviani et al., 2023). In most of these tasks, the measurement of approach behaviors consisted in the recording of attentional capture through eye-tracking devices. In other words, sign-tracking was still interpreted as incentive salience attribution to a cue, but characterized as privileged attention given to the CS versus the reward location. The translational aspect is that eye gaze is an analog or a proxy of approach behavior in humans (Stephens et al., 2010). Except for the use of eye-tracking measurements, virtual PCA tasks are therefore very similar to ST/GT animal models. The results of these studies were disparate, successfully identifying ST/GT groups but not always succeeding in confirming previously reported relationships between sign-tracking and other behaviors (substance use, impulsivity, ADHD, risky choices). Neuroimaging results (Ottaviani et al., 2023) suggesting a subcortical control in sign-tracking behavior and a more cortical influence in goal-tracking behavior, is consistent with findings from the animal literature (e.g., Flagel et al., 2011).

VMAC tasks have been the most widely used method to investigate human sign- and goal-tracking behaviors, although this purpose is not always explicitly stated. Several versions of this task were published, drawing or not a parallel with the ST/GT paradigm. In contrast to animal studies, in which sign-tracking is measured through direct approach behavior in a Skinner box, the VMAC task measures the extent to which a signal for reward comes to exert control over behavior through attentional bias (Watson, Pearson, Most, et al., 2019). Most VMAC studies used reaction times as the dependent variable to infer attentional capture to a reward-associated CS. This automatic capture of visual attention is supposed to reflect incentive salience attribution, acting outside volitional control (Colaizzi et al., 2020), and hence might be an analog of sign-tracking behavior in humans (Le Pelley et al., 2024). Interestingly, eye-tracking devices were implemented in some versions of the VMAC tasks, making the procedure quite similar to virtual PCA tasks. Several studies have consistently demonstrated the presence of automatic attentional biases for reward-associated cues. The cognitive mechanisms underlying the VMAC effect are undoubtedly related to the incentive salience attribution involved in sign-tracking behavior. Accordingly, the few VMAC studies which tried to draw a parallel with ST/GT experiments found compatible results with the animal literature (Duckworth et al., 2022; Liu et al., 2021; Watson et al., 2023). Overall, VMAC studies have shown that reward-related cues can bias human attentional capture, especially in some individuals, suggesting that humans also show individual variations in the sensitivity to a CS associated with reward delivery. Moreover, impulsivity, risky alcohol use, and other addiction-related behaviors have been shown to be associated with this reward-related attentional bias (Albertella et al., 2021; Albertella, Watson, et al., 2019; Liu et al., 2021; Watson et al., 2023). However, in its usual configuration, the VMAC procedure differs from the ST/GT animal model in several respects (see below).

Miscellaneous alternative paradigms were also devised to measure sign-and goal-tracking in humans. To date, however, those latter models still lack validation studies and replications to properly assess their potential contribution to the study of these behaviors in humans. It is noteworthy, however, that the gamification of the traditional autoshaping procedure might be a thoughtful and innovative way to translate the ST/GT animal model in humans, while maintaining sufficient face validity.

Physical Approach Behaviors vs. Visual Attention Capture

On a strictly translational perspective, measuring sign- and goal-tracking behaviors in humans should involve some kind of approach or contact with a touchable, predictive cue and a reward delivery location. In the standard ST/GT animal paradigm with rodents, a retractable lever is used as the reward-associated cue and physical interactions with it are recorded as sign-tracking behavior (Flagel et al., 2007; Meyer et al., 2012). However, few of the reviewed human studies used approach behavior or direct contact with the CS as the sign-tracking measure, except for the physical PCA tasks. As already mentioned, it is not easy to implement a task with physical contact in humans without giving specific instructions to the participants. This is probably why most human ST/GT studies replaced direct contact by the recording of visual attention toward the CS, most often using eye-tracking devices. Attentional capture by the reward-associated cue is then considered as a visual analog of approach or sign-tracking behavior. Attentional capture is therefore the strategy underpinning most virtual PCA tasks, all VMAC studies and some of the unclassified experiments. A major advantage of this procedure is that attentional capture is automatic and difficult to control by the participants. Indeed, VMAC studies demonstrated that the attentional bias for high reward-associated cues persists even when looking at it causes reward omission (Le Pelley et al., 2015; Pearson et al., 2020; Watson, Pearson, Theeuwes, et al., 2020).

There is currently little experimental demonstration that attentional capture is a proper equivalent of physical contact to assess sign-tracking behavior. Very few studies have investigated whether these measures are strongly correlated in the context of the ST/GT paradigm. Cope et al. (2023) tested both eye-tracking and behavioral measures to compute ST, GT, and intermediate profiles. They showed a positive, but non-significant, correlation between lever gazes and lever presses. Joyner (2019) combined measures of direct physical contact, proximity, and head orientation towards a lever CS and food magazine in children. They obtained significant correlations between the measurement indices and significant agreements for the classifications based on these indices. Based on these few findings, attentional capture seems to be an adequate visual analog of approach behaviors to investigate sign-tracking in humans. Given that most human experiments use attentional versions of the ST/GT tasks, further studies are required to validate this measurement procedure.

Translational Assessment of the Human ST/GT Models

From the present review, it was clear that some of the human studies were further away from the ST/GT animal model than others. Five translational exclusion criteria were defined, although all studies claiming to study human sign- and goal-tracking (and not always in agreement with these criteria) were included in the present review (Table 2, Appendix 4). These translational criteria can therefore be used to assess how comparable these studies are to the ST/GT animal model. A perfectly valid translational human analog of the ST/GT animal model should comply with these criteria. Accordingly, a human ST/GT model should: 1) experimentally establish the association between the CS and the reward, 2) oppose sign- and goal-tracking behaviors or learned strategies, 3) avoid requiring an instrumental behavior to obtain the reward, 4) reward the participant with positive reinforcements and 5) implement a direct measure of the attractiveness or incentive salience of the CS and reward.

When based on attentional capture, sign-tracking results from incentive salience attribution to the reward-associated cues and might therefore be considered as a form of attentional bias. However, attentional bias studies usually investigate the effects of natural cues that were repeatedly associated with rewards in real life, such as alcohol brands, food brands, and drug-related objects. Yet, such previously learned associations between a CS and a reward are not optimal for detecting ST and GT phenotypes in the laboratory. Indeed, controlling the frequency of exposure to a specific cue-reward association that occurred in real life is virtually impossible. When the goal is to identify ST and GT phenotypes, it is therefore very important to test sign- and goal-tracking behaviors learned in standard experimental conditions. Some of the reviewed human studies, especially from the unclassified category, labelled participants as ST or GT based on their response to a real-life preexisting CS. It is currently unknown if and to what extent such classifications would overlap with categorizations based on the sign-tracking behavior observed in standard experimental conditions. Transposing sign-tracking to real life is certainly an essential step in validating the model in humans. But this step should come after the thorough investigation of the original paradigm.

The need for an actual contrast between a sign (CS) and a goal (reward location) is essential to properly translate the animal ST/GT paradigm in humans. In animal studies, the sign (usually a retractable lever) and the goal (usually a food magazine) are physically distant. They cannot be approached simultaneously, such that the animal must decide which one is the most attractive (Boakes, 1977). The identification of ST and GT phenotypes is precisely based on a competition between the CS and the reward delivery location. In the initial VMAC tasks (Le Pelley et al., 2015), the target stimulus is a discriminative cue indicating which keyboard key is the right instrumental response. Clearly in that procedure, it is possible to determine how attractive the CS is for a specific participant. This is measured through the delayed response time when the CS is shown along with the target stimulus. But the procedure does not directly contrast a sign and a goal and cannot consequently classify participants as STs or GTs. Furthermore, in many VMAC studies, the effect of the distractor cue is tested in extinction, i.e., when no more reward is available. In those studies, rewards are delivered only during the training phase, whereas the effect of the distractor is measured in a testing phase without reward (Pearce et al., 2022). This prevents any contrast behaviors between a “sign” and a “goal”. Moreover, at that point, the “sign” has lost its “signaling” value, since no reward is delivered. As mentioned in the introduction, this aspect was part of our exclusion criteria. However, this procedure has been extensively used in the literature and has highlighted several connections between the VMAC effect and psychological disorders, such as depression, opioid addiction, ADHD, obsessive-compulsive disorders, and risk-taking in HIV+ individuals (for reviews see Anderson, 2021; Le Pelley et al., 2024). Moreover, the attractiveness of the “goal” is not directly measured in the initial VMAC task. What is indirectly measured is the attention paid to the distractor, which is inferred from a delayed response time to the target stimulus. It is currently unknown whether sign- and goal-tracking behaviors indirectly inferred from such delayed response time would correspond to more traditional measures based on approach behaviors or direct attentional capture.

The animal ST/GT paradigm relies on Pavlovian conditioning. No response is required from the animals to obtain the reward. Also, sign-tracking behavior has no positive or negative consequences in the standard paradigm. The distinction between Pavlovian and instrumental conditioning is important since they are not driven by the same underlying mechanisms. However, many VMAC studies involve instrumental behaviors, significantly departing from the ST/GT animal model (see table 2, Appendix 4). In VMAC studies, the CS-reward relationship is Pavlovian. The colored distractor predicts reward magnitude and no action towards this CS is required to succeed in the task (Le Pelley et al., 2024). However, the VMAC procedure also involves a specific instrumental response towards a target stimulus to obtain the reward. Moreover, the task often includes an additional instrumental component in the form of some punishment for responding to the CS or for too slow responding to the target. All reviewed VMAC studies involve a time limit beyond which no reward is delivered. In eleven of those VMAC studies, a punishment (reward omission) is also administered for looking at the CS. Some other VMAC studies also punish wrong responses or make the reward magnitude dependent on reaction time. The consequences of such methodological decisions are still unknown and would require specific studies to conclude that the VMAC procedure is a genuine human analogue of the ST/GT animal model.

Most ST/GT animal studies are based on positive reinforcement conditioning, using food as a reward. It is theoretically possible to study aversive sign-tracking, especially when approach behavior is replaced by attentional capture. However, we decided to focus on sign-tracking in relation to reward predicting cues since this has been linked to addiction vulnerability. As shown in Figure 3, human sign-tracking studies used several types of rewards: monetary, fictional, or food. Moreover, in some studies, no reward was delivered during the experiment (e.g., Salmeron, 2020; Nelson et al, 2020).

Identification of ST and GT Phenotypes in Humans

One of the major observations resulting from the ST/GT animal model is the individual variability in the tendency to develop sign-tracking behavior (see Flagel et al., 2007, 2008, 2009). On this basis, individual animals have often been classified as STs or GTs, suggesting that these categories reflect stable phenotypes (Gillis & Morrison, 2019). As shown in Figure 4, sixteen studies tried to categorize human participants according to their tendency to develop sign-tracking. Most of these studies (75%) used physical or virtual PCA tasks. The most common procedure to create ST/GT categories was through tertile (or median) split computed on “response bias scores” toward the CS, although some studies also used alternative methods such as latent profile analysis (Cope et al., 2023; Versace et al., 2016). Few studies included a third (intermediate) category for individuals whose behavior alternated between sign- and goal-tracking. In general, the nature of the “response bias score” from which the categories were defined is highly heterogeneous. In PCA tasks, the categories are typically established from the number and latency of physical contacts with (or gazes to) the CS vs. the reward location (e.g., Colaizzi et al., 2023; Cope et al., 2023; Dinu et al., 2024). However, in VMAC studies, the categories are defined by the differences in reaction times for high vs. low rewards (Duckworth et al., 2022; Liu et al., 2021). Some studies also created categories based on behaviors toward a CS without any reward delivered during the task (e.g., Nelson et al., 2022). It is currently unknown whether these various categorizations overlap or even whether they assess the same underlying processes.

The animal literature shows that several experimental parameters may significantly alter sign and goal preferences, and thus the proportion of individuals within the ST, GT, and INT categories. For instance, the type of US (e.g., water vs. food) and the mode of US delivery (e.g., intravenous vs. oral) seem to alter the way individuals approach or interact with the CS, respectively in pigeons (Jenkins & Moore, 1973) and rodents (Uslaner et al., 2006). CS duration and CS-US interval (Holland, 1980), reward predictability (Anselme et al., 2013), inter-trial interval (Mahmoudi et al., 2023), as well as the nature of the CS (a lever vs. a tone) (Meyer et al., 2014), also impact the proportion of STs (and GTs when assessed) in rodents. Unfortunately, few human studies have tested such variations in the parameters. Additionally, there is little consensus and comparability on these parameters between human studies. For instance, we have already pointed out in this review that the type of reward strongly varies between human ST/GT studies. Another parameter that must be considered is CS duration, for which strong variations in experimental design were noted (e.g., 8.3 s in Colaizzi et al., 2023; 5 s in Garofalo & di Pellegrino, 2015; 3 s in Cope et al., 2023). Examining the impact of these methodological choices in human participants may help to establish a human paradigm able to maximize individual variability in the attribution of incentive salience to reward cues. In summary, there is an obvious lack of replication and validation studies, making it difficult to conclude that stable ST and GT phenotypes exist in humans. In rats also, the idea that the ST and GT phenotypes are stable traits of individuals, insensitive to environmental factors, is controversial (e.g., Meyer et al., 2014; Robinson et al., 2015). In addition to varying the contexts in which both phenotypes are tested, better consensus on the experimental parameters and on the way to analyze the available data would help clarify the interpretations.

Relationships Between Human Sign-Tracking Behavior and Other Variables

In the animal literature, relationships between sign-tracking behavior and other individual variables have been established, leading to the suggestion that sign-tracking might be a risk factor for several psychological disorders in humans. In rodents, the ST phenotype has been repeatedly associated with addictive behaviors (Saunders & Robinson, 2011; Tomie & Morrow, 2018). In humans, several studies also show significant associations between sign-tracking and drug or alcohol consumption (Albertella et al., 2017, 2021; Albertella, Watson, et al., 2019; Schettino et al., 2022; Watson et al., 2023), although negative results were also reported (Doran, 2016). Clearly, further research is needed to substantiate the association between sign-tracking and drug or alcohol addiction. Rodent studies also repeatedly showed that the ST phenotype is characterized by higher impulsive tendencies (Lovic et al., 2011; Tomie & Morrow, 2018, although see Flagel et al., 2010). However, in the reviewed human studies, this effect is far from clear. Some studies show a positive correlation between sign-tracking and impulsivity (Colaizzi et al., 2023; Cope et al., 2023; Doran, 2016; Garofalo & di Pellegrino, 2015; Schettino et al., 2022), while others failed to show any association (Colom, 2023, chapter 8 and 9; Doran, 2016; Joyner, 2019). Drawing firm conclusions on impulsivity from current studies is difficult, given the poor consistency in the methods used to measure sign-tracking. Finally, sign-tracking has been shown to induce poor attentional control in rodents (Paolone et al., 2013). Preliminary evidence suggests similar effects between sign-tracking-like behavior and some aspects of attentional control in humans (Albertella et al., 2017; Serrano-Barroso et al., 2022), although these findings require further investigation.

Limitations

Given the great heterogeneity in definitions, terminology and methodology, searching and summarizing studies on sign-tracking in humans is a challenge. Although several search terms were used in order to get all relevant information, we might have missed potentially relevant studies. Nevertheless, we believe that this review provides a pretty comprehensive map of what has been done on human-sign-tracking.

Conclusion

The ST/GT model and its implications for human addiction date back to several decades (Boakes, 1977; Brown & Jenkins, 1968; Hearst & Jenkins, 1974; Tomie, 1996; Tomie et al., 1998), although its translation to humans is quite recent. Until now, the techniques implemented vary greatly on crucial methodological aspects such as the type of reward used, the existence of a ST/GT categorization or the dependent variable taken into account (physical approach of cues, eye gaze, reaction time measures, etc.). In this review, we identified four major categories of methods used to study human sign-tracking. Their detailed examination indicated the high heterogeneity that characterizes this literature, and we suggested five criteria that we think are important for a good translational ST/GT model. Few replication and validation studies have been published until now and further research is necessary to create a better consensus on how to measure sign- and goal-tracking behaviors in humans.

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The authors have no competing interests to declare that are relevant to the content of this article.

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Consent to Participate

Not applicable.

Consent for Publication

Not applicable.

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There is no data available because it is a theoretical review.

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No data or materials are available for this article. The protocol of this scoping review was preregistered on OSF registries, on the following link: https://osf.io/utfcq/.

Author Contributions (CRediT)

MH: Conceptualization, investigation, writing- original draft preparation, visualization, project administration, data curation, formal analysis. **ND:** Conceptualization, Methodology, writing- review & editing, validation. **PA:** Supervision, writing-review & editing, investigation. **EQ:** Supervision, writing-review & editing, investigation.

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References marked with an asterisk indicate studies included in the scoping review.

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Figure 1

Number of Studies on Human Sign- and Goal-Tracking or Closely Related Behaviors Over Time.

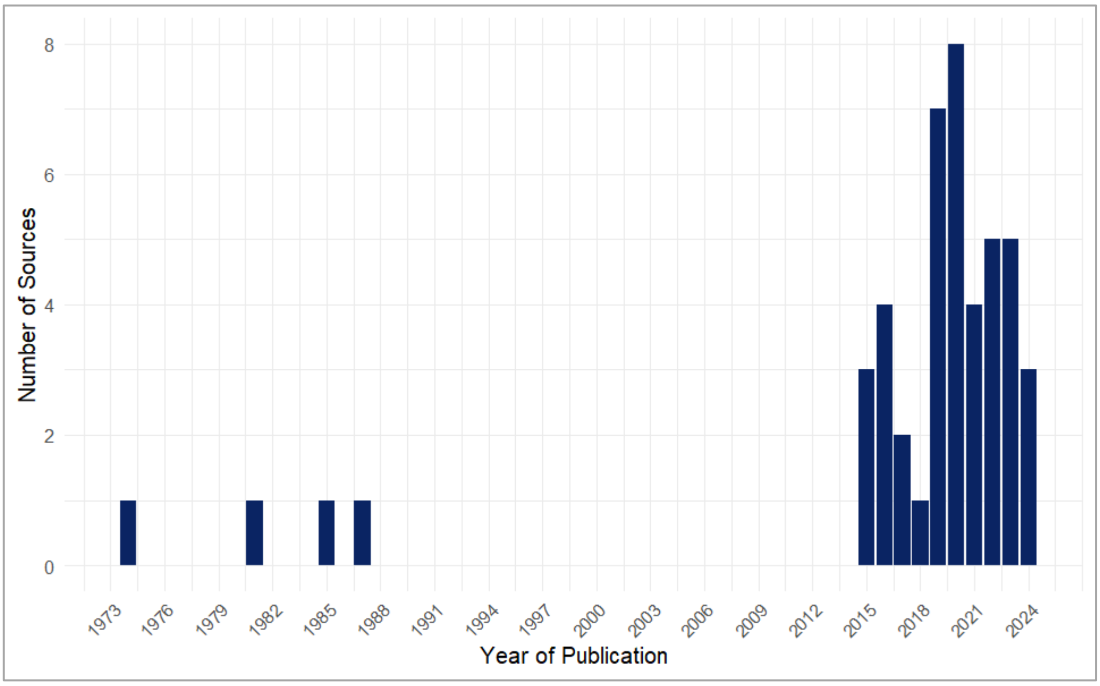
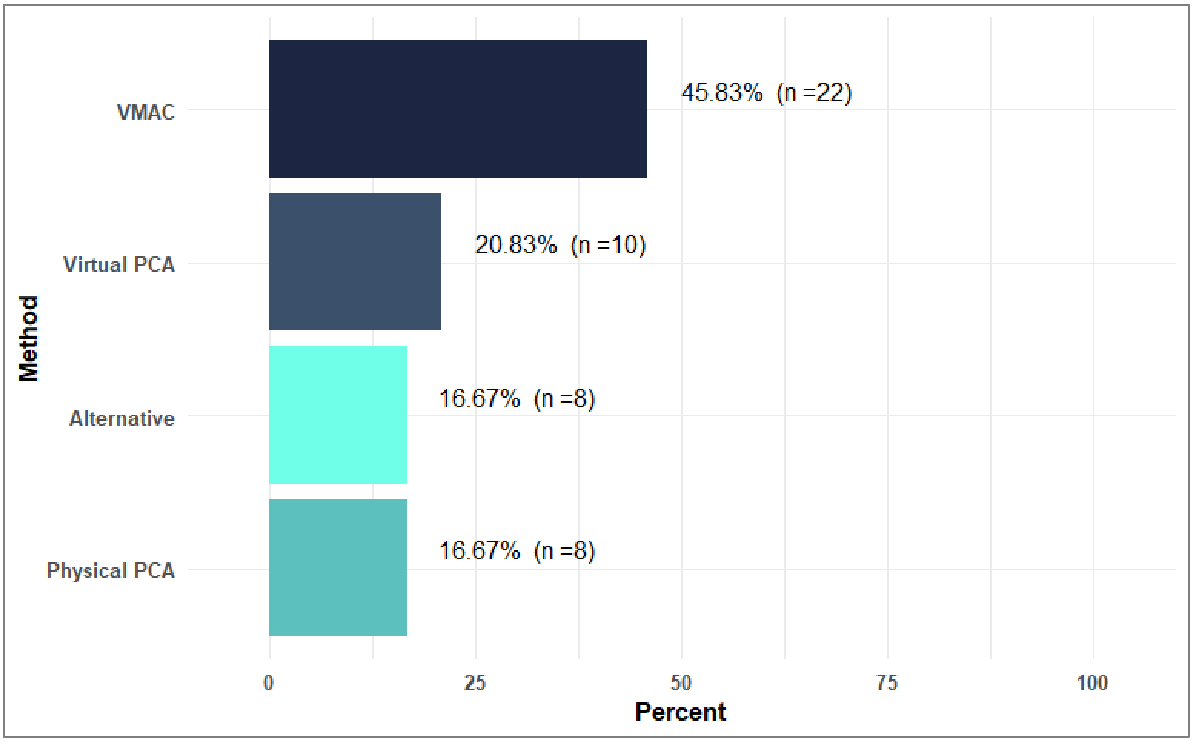


Figure 2

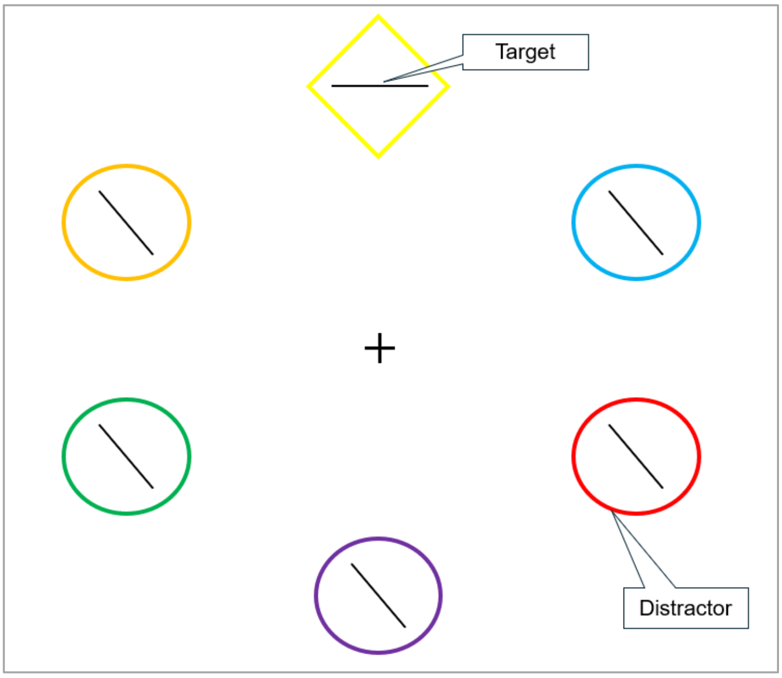
Distribution of Studies in the Four Major Categories of Paradigms Used to Implement/Measure Human Sign-Tracking or Its Analog in Humans, Included in This Review (N= 48).



Note. VMAC= Value-modulated attentional capture, PCA= Pavlovian conditioned approach

Figure 3

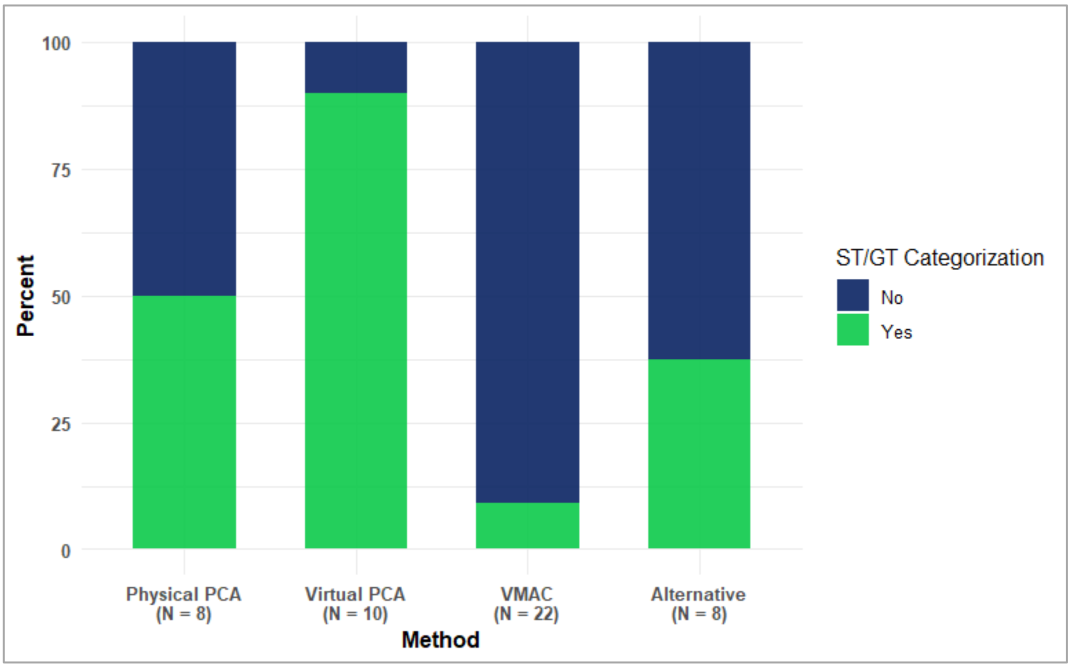
Layout of a VMAC Task



Note. The diamond shape is the participants' target, they need to indicate the orientation of the inner line (horizontal vs. slashed). The red circle is the distractor, announcing the reward magnitude available if the participant gives a correct response. Adapted from Pearce et al., 2022.

Figure 4

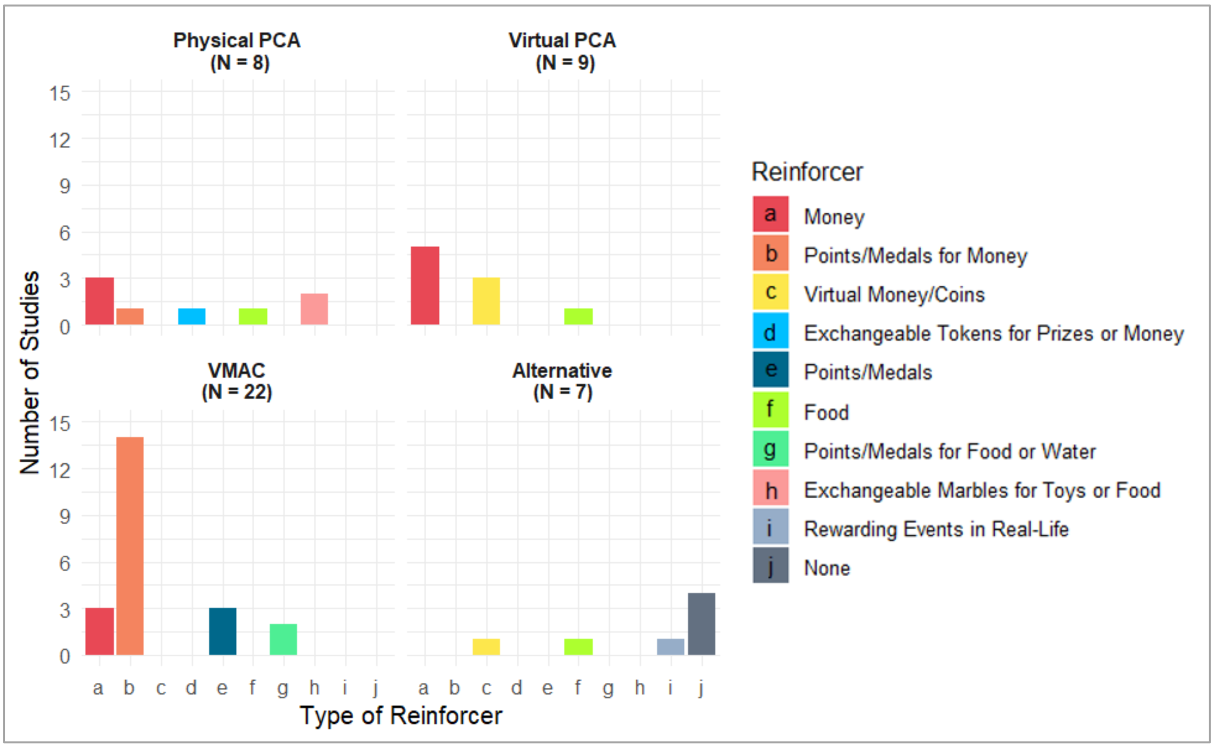
Percentage of Studies That Categorized ST/GT (or Other) Profiles for Each Subtype of Method.



Note. PCA= Pavlovian conditioned approach; VMAC= Value-modulated attentional capture. Studies that investigated categories of individuals are represented by the bottom bar (green in color version), those that did not, by the top bar (dark blue in color version).

Figure 5

Distribution of Reward Types Used in Each Subtype of Experimental Paradigm Implementing Human Sign- and Goal-Tracking.



Note. PCA= Pavlovian conditioned approach; VMAC= Value-modulated attentional capture. Schad et al., 2023 and Schembre et al., 2016 were not included in this graph, due to missing information about the reward type.