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ORIGINAL RESEARCH

A Neurobiological-Behavioral Approach to Predicting and Influencing Private Events

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Abstract

The primary goals of behavior analysis are the prediction and influence of behavior. These goals are largely achieved through the identification of functional relations between behaviors and the stimulating environment. Behavior–behavior relations are insufficient to meet these goals. Although this environment–behavior approach has been highly successful when applied to public behaviors, extensions to private events have been limited. This article discusses technical and conceptual challenges to the study of private events. We introduce a neurobiological-behavioral approach which seeks to understand private behavior as environmentally controlled in part by private neurobiological stimuli. These stimuli may enter into functional relations with both public and private behaviors. The analysis builds upon several current approaches to private events, delineates private behaviors and private stimulation, and emphasizes the reciprocal interaction between the two. By doing so, this approach can improve treatment and assessment of behavior and advance understanding of concepts such as motivating operations. We then describe the array of stimulus functions that neurobiological stimuli may acquire, including eliciting, discriminative, motivating, reinforcing, and punishing effects, and describe how the overall approach expands the concept of contextual influence. Finally, we describe how advances in behavioral neuroscience that enable the measurement and analysis of private behaviors and stimuli are allowing these once private events to affect the public world. Applications in the area of human–computer interfaces are discussed.

Keywords Private events · Human–computer interface · Neuroscience · Contextual control · Thinking · Covert behavior

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A major goal of behavior analysis is the identification of functional relations that enable the prediction and influence of behavior (Skinner, 1953; Watson, 1913). As such, our scientific analyses extend from the behaviors of interest to environmental events of which they are a function. This approach has made behavior analysis highly successful in predicting and influencing overt, observable behaviors (Heward et al., 2022). Extensions to covert or private events, however, have proven more difficult and much less common (Anderson et al., 2000; Friman et al., 1998), which is problematic given that much human behavior is largely private (e.g., thinking, emotions).

Observable, public behaviors occur and change the environment in ways that are easily observed by others. The relevant stimulating environment is observable and manipulable. For example, we may observe a young child who screams when their parent is talking to another adult and find that screams tend to produce parental attention. In this case, the environmental "causes" are clear, and statements of functional relations are easily made. The child's screaming is likely in a functional relation with various contextual variables such as deprivation of attention, discriminative stimuli including parental presence, and consequent events including the production of attention. This analysis affords both prediction and influence of the behavior of screaming. One could predict screaming will occur when attention is withheld yet available, and one could influence future screaming by withholding or providing attention contingent on the behavior.

The philosophy of radical behaviorism assumes all behavior has a cause, including private behavior (Delprato & Midgley, 1992; Skinner, 1953). Private events differ from public events only in their detectability (Skinner, 1953, 1969). Although the role of private events in the analysis of behavior has been a topic of some debate (e.g., Anderson, 1997; Anderson et al., 2000; Baum, 2011; Palmer, 2011, Schlinger, 2011), the predominant view is that inclusion of these events is important for the overall understanding of behavior (both public and private). Palmer (2009, 2011), for example, argues that although private events cannot be included in an *experimental* analysis, they may still be important in the overall *interpretation* of behavior provided the inferred private events are based on experimentally established principles. Consider a young child with a communication deficit grinding her palm into her right ear. A practitioner may be unable to see either the infected eardrum that is causing the discomfort or the reduction in pain produced by the grinding, but can nonetheless develop an actionable theory by inferring these private stimulations. Although the use of an otoscope would make the private stimulation public and accessible for experimental analysis, it is not required for the successful influence of palm grinding. Although some behavior analytic research has addressed private events (e.g., Mandavia et al., 2015; Moore et al., 2022; Palmer, 2011), and researchers have called for more (e.g., Friman et al., 1998), such work is dwarfed by behavior analytic research on public behavior. Further, attempts to incorporate private events tend to inadvertently imply functional relations between behavior and other behaviors (i.e., behavior–behavior relations) rather than between the environment and behavior (environment–behavior relations).

The Problem of Behavior–Behavior Relations

To influence behavior, we must be able to manipulate the variables of which behavior is a function. The behavior of an organism cannot be the cause of other behaviors of the same organism. Even in examples of "self-control" it is the organism's behavior that changes the *environment* to influence future behaviors. When a person sets an alarm to remind themselves to exercise, it is the alarm, among other environmental stimuli, which evokes exercising. Any attempt to influence behavior constitutes an alteration to the organism's environment. Thus, the identification of a "cause" must begin and end beyond the organism's own behavior (Hayes & Brownstein, 1986).

This is true even in the event of relatively fixed behavior chains (e.g., making coffee), where it may appear that one behavior (e.g., scooping coffee) causes the next behavior (e.g., pressing the "on" button). Although the individual responses in a sequence may occur with high correlation, one after the other, the ultimate source of control of the behavior remains in the environment. Each response in the sequence alters the environment, and this alteration serves as both a potential reinforcer for the prior response and a discriminative stimulus for the next response. The "on" button is pressed not because scooping just occurred, but because the environment now consists of a coffeemaker filled with coffee. A person encountering a prefilled coffee maker, for example, will simply press "on" despite not having previously emitted scooping behavior because the necessary environmental events are present. Even in the instance of a seemingly unitary response, such as reaching for a cup of coffee, the environment is continually altered by incremental movements of the hand (e.g., the hand occupying a specific physical space in relation to the coffee cup) in ways that may influence further movement.

The environment includes variables that exist external (e.g., a stop sign) and internal (e.g., feelings of nausea) to the organism, and the location of these variables does not denote a different kind of influence. "We need not suppose that events which take place within an organism's skin have special properties [compared to events that occur outside the skin]" (Skinner, 1953, p. 257). However, the search for these environmental variables can lead to seemingly nebulous and often diffuse causes of behavior. For example, the circadian rhythm is influenced by variables outside the skin (e.g., light level, caffeine, noise; Czeisler, 2013), but will persist in the absence of these external variables (e.g., Schwartz & Klerman, 2019) indicating additional sources of influence. Fully understanding the sleep–wake patterns of an individual requires these sources to be identified, and likely requires analysis of multiple sources of influence including learning history, current contextual events (internal and external), as well as genetic influences.

When analyzing behavior, we may indeed note the existence of behavior–behavior relations, such as alarm setting and exercising, or scooping coffee and pressing "on." These behavior–behavior relations, however, only enable the prediction of behavior—if this behavior occurs then that behavior is likely to occur. This analysis does not lend itself to the influence of behavior. Not only are we left with the question of why the first behavior occurred, but we are unable to influence the behavior of interest without first influencing other behavior. The goal of behavior *influence* is impossible without an analysis that links behavior to an environmental (i.e., nonbehavior) event that is manipulable in principle if not in practice.

Further, given that behavior is always the interaction between the whole organism and a stimulating environment (Kantor & Smith, 1975, Schnaitter, 1975, Skinner, 1974), to look at either separately is to enter a different domain or discipline than behavior analysis. To analyze only the organism (e.g., biological structures), for example, is perhaps to enter the domain of biology. Although biological structures interact in overall behavior, these structures are merely physical parts of the whole organism and any resulting analysis is perhaps mechanistic, not functional or contextual (Hayes et al., 1988; Morris, 1993; Moxley, 1992). Whereas a mechanistic analysis seeks to explain how different parts of an organism or system affect one another (e.g., how bicep contraction and triceps relaxation result in elbow bending), a functional analysis seeks to understand the history and context in which an organism behaves (e.g., what are the conditions under which elbow bending occurs and has occurred). Behavior analysis as a complete domain is the study of the interaction between both the stimulating environment and the whole organism.

Although behavior analysts have successfully applied a functional approach when analyzing publicly observable behavior, the analysis is underdeveloped in application to private events (e.g., thinking). This article will describe technical and conceptual challenges to incorporating private events into an analysis of behavior. We then discuss current conceptually systematic approaches to understanding private events and propose a neurobiological-behavioral analysis that coheres with and builds upon these approaches, emphasizes the importance of distinguishing between private behaviors and private stimulation, and highlights the reciprocal interaction between these events. We highlight the strengths of this approach through an application example and describe how the approach can improve treatment and assessment as well as advance understanding of concepts such as motivating operations. We then describe how neurobiological stimuli can acquire a variety of functions, and how the overall approach represents an expansion of the concept of context. Finally, we describe recent technological advances that are increasing the observability of private events, align with the neurobiological-behavioral approach, and extend the impact of private events on public environments.

Technical Challenges Extending Behavior Analysis to Private Events

Behavior analysis, as a natural science (Marr, 2009), adheres to the monistic position that everything that occurs is a physical event (Boring et al., 1945, Delprato & Midgley, 1992). As such, all events are, in principle, detectable and open to investigation. The term *private events* commonly refers to either behaviors or stimulating events that are not readily available for observation (see Skinner, 1984). We use the term *private events* when referring broadly to unseen behaviors or stimuli, but the more specific terms *private behaviors* or *private stimuli* when referring individually to either aspect of the functional relation. In this respect, the qualifier *private* refers to an event that is currently unobservable. As an event becomes observable it loses the private qualifier, at least for the time being. It may yet become private again should detection be lost. In practice, private events are often largely undetectable or minimally detectable given current technological capacities. For example, although most smartwatches allow for the detection and measurement of heart rate, there is minimal equivalent technology in regard to thoughts and emotions. At some point, it may be possible to entirely do away with the term private. Although behavior analysis is moving in that direction, we have not yet arrived.

Current technological limitations have led some to rely on verbal self-reports of private events. An individual can describe, with some degree of accuracy, private events within the skin. For example, when asked the question, "How are you feeling," an individual could accurately describe feeling nausea. In this respect, the verbal report could be said to be partly under the influence of private stimulation (e.g., a tact; Skinner, 1957). At a practical level, practitioners may need to rely, in part, on verbal self-reports of private events due to the lack of reasonable alternatives. However, although verbal self-reports can be a reliable means to gather information about some private events, there are limitations. Not only can the verbal response come under the influence of other stimuli, leading to an inaccurate report (Skinner, 1957), but these events may also occur without the individual's "awareness" or ability to report.

Behavior analysts seek to identify functional relations between behaviors and environmental events, but either or both may be private at any given time. Functional relations could exist between (1) private stimulating events and public behaviors (e.g., when a full bladder results in seeking out a toilet); (2) public stimulating events and private behaviors (e.g., when a sign reads, "last toilet for 100 miles" and evokes the thought, "I better use the toilet now"); or (3) private stimulating events and private behaviors (e.g., when the fullness of a bladder evokes the thought, "I'd better not drink any more water"). Situations where one or more component of a functional relation is private pose a problem for behavior analysis. Although private events may be included in the overall *interpretation* of behavior, these events do not play a role in the experimental analysis of behavior (Palmer, 2009). An experimental analysis requires the events be made public and available for manipulation, and this frequently necessitates sophisticated instrumentation that, though quickly developing, is nevertheless still limited.

Conceptual Challenges Extending Behavior Analysis to Private Events

Skinner saw no significant difference in the nature or function of either private stimuli or private behavior. "A small but important part of the universe is enclosed within the skin of each individual and, so far as we know, is uniquely accessible to him. It does not follow that this private world is made of any different stuff—that it is in any way unlike the world outside the skin or inside another's skin. Responses to private stimuli do not appear to differ from responses to public events" (Skinner, 1957, p. 130).

Although this conceptualization of private events is conceptually systematic, in practice the distinction between what constitutes private behavior and private stimuli is not always clear. Further, for behavior analysts largely trained in the identification of external sources of influence, confusion around the nature of private behavior and private stimuli can result in faulty analyses. One such error is a tendency to posit behavior–behavior relations when attempting to analyze these "small but important" private events.

Consider common behavioral explanations of private problem-solving. When a person is faced with a problem to which no solution is readily apparent the person may engage in problem-solving behavior. This is understood as behavior that alters the context of the problem by creating new discriminative stimuli or otherwise supplementing or manipulating the private context. The person is then able to respond more successfully to this newly modified context (Axe et al., 2018; Donahoe & Palmer, 2004; Skinner, 1957, 1968).

For example, a person may be provided a novel math problem that they must solve privately. An analysis might suggest that the person privately "tests out" a series of possible solutions, rejecting each until finally arriving at the correct solution and only then publicly stating the answer. One might argue that, through an extensive learning history, privately visualizing one step of solving the problem produces visualizations of the next step, and these visualizations serve as private discriminative stimuli for future steps. Further, privately visualizing the correct solution functions as reinforcement for the overall sequence of private problem-solving behaviors.

This explanation, however, is insufficient as it is built on a series of behavior–behavior relations. No environmental events are invoked in the analysis. Both the private problem-solving and the private visualizing of the solution are behaviors of the same organism, but private visualizing is reinterpreted as a stimulating event. Contrast this with an analysis of the *public* problem-solving of a math problem, where a person is writing out their method. Here, we would point to the written products as functionally related environmental events. It is the impact of the writing behavior on the environment (i.e., the creation of a correct number written on paper), which functioned as reinforcement for the problem-solving. We would not suggest the writing of the solution (akin to private visualizing of the solution) was reinforcement for the problem-solving. In the analysis of private problem-solving, no such impact on the environment is implied.

Another example of problematic behavior-behavior explanations may be seen in the analysis of anxiety. Take an example of a child who was bitten by a dog, and is now anxious around dogs (e.g., increased heart rate, sweating, hyper-vigilance) and also reports becoming anxious merely thinking about dogs. An explanation might be put forth that the child is anxious around the physical dog due to the bite, and that this fear has generalized to all physical dogs. It might further be suggested that the *thought* of a dog had been previously associated with physical dogs, and therefore now evokes anxiety as well (e.g., Dymond et al., 2017; Kelly & Kelly, 2021). In this account, the function of one stimulus (pain from a dog bite) could be said to transform the function of thinking about dogs, and these thoughts come to function as antecedent stimuli evoking the behavior of emotional distress. The concern with this explanation, however, is that thinking about dogs is a response of the child, not a stimulus to which the child is responding. These thoughts, therefore, cannot acquire stimulus functions or serve directly as an influencing antecedent for further behavior such as anxiety.

Conceptually Systematic Approaches to Private Events

Private behaviors are fundamentally like any other behavior and must correspond to our understanding of behavior which is "that portion of the organism's interaction with its environment that is characterized by detectable displacement in space through time of some part of the organism and that *results in a measurable change in at least one aspect of the environment* (Johnston & Pennypacker, 1980, p. 48; emphasis added). If this change in the environment is something the organism can respond to, it can theoretically acquire some stimulus function given an adequate learning history. The environment/context includes both the private and public worlds, and Skinner (1969) suggests, "the skin is not that important a boundary. Private and public events have the same kinds of physical dimensions" (p. 228). This being the case, consistent with behavioral theory and neuroscientific research, private behaviors may produce private environmental changes, and these changes have the potential to enter into a functional relation with other behavior—private or public. As behavior analytic extension to private events is a relatively new area, it is important that the analysis remains conceptually systematic. As noted by Skinner (1953), "confusion in theory means confusion in practice" (p. 9).

With currently available and developing technologies, particularly in neuroscience, events that were once only private and inferred are increasingly made public. As this occurs, these events become available for experimental analysis and the establishment of functional relations. Biological functioning has increasingly been incorporated into the overall interpretation and analysis of behavior. Donahoe and Palmer (2004), for example, present a "biobehavioral approach" that incorporates intra-organismic *subbehavioral* events (e.g., physiological events; neural activity) as important mediators of behavioral events. This approach suggests that "functional relations between the environment and behavior are supplemented with functional relations involving subbehavioral events" (p. 10). It is important to note that these events are not inferred processes but rather are established through experimental analysis. A person saying someone's name upon seeing their face, for example, might be considered as behavior mediated by a combination of subbehavioral (e.g., experimentally identified neural activity) and environmental factors, in conjunction with a learning history. It would not be explained by processes such as memory, retrieval, or information storage, which (among other considerations) are inferred processes.

Thompson (2007) suggests that behavior is best understood as a functional system interacting with other functional systems, including biological systems and related endogenous variables. Thompson discusses several behavioral functions involving biological systems, including motivating operations, discriminative functions, and reinforcement. For example, administration of certain drugs can function as potent reinforcers. However, if related brain receptors are blocked with an antagonist, the same drug administration ceases to function as a reinforcer, and relevant operant behavior undergoes extinction. This highlights the importance of consideration of these biological systems; a complete accounting of the drug–behavior functional relation would be limited otherwise.

Even when a private response of interest ultimately remains private (i.e., is not yet detectable by technology) it may still be possible to conduct meaningful experimental analyses by incorporating neuroscientific measures of correlated neural activity. Measures of event-related potentials (ERP; electrical activity in the brain evoked by a specific stimulus and preceding much observable behavior), for example, may be used as proxy measures for behavior that is otherwise unobservable (Ortu, 2012). The P3 wave is an ERP that is involved in decision making and evoked approximately 300 ms from the presentation of a relevant stimulus. If a person is repeatedly presented with math problems, for example, and required to privately select the correct answer when it is displayed on a computer screen, measurement of the P3 ERP would likely show evoked activity prior to any selection behavior and only when the correct answer was present. No P3 ERP activity would be likely in response to incorrect answers. Although this P3 activity should be interpreted cautiously and does not conclusively indicate the person is privately responding in a specific way (e.g., thinking "that's the answer"), it could be a useful alternative in situations involving otherwise undetectable behaviors. In practice, for example, it could be used to assess the mathematic ability of a person for whom public selection of the correct answer was impaired. Further, ERPs can be observed and influenced at the individual level, allowing for experimental demonstration of functional relations. Although neuroscientific measures, such as that of the ERP, do not wholly resolve issues of privacy, they do lower what Palmer (2009) refers to as the "threshold of observability."

Private events are conceptually relevant to the study of behavior. Further, these events are increasingly available for experimental analysis as advances in technology render them public. The benefits of incorporating findings from relevant disciplines, such as neuroscience, into an overall behavioral accounting are clear. Collaboration between behavior analysis and neuroscience appears to be fertile ground as the two disciplines are aligned in their adherence to a selectionist framework (Donahoe, 2017; Ortu & Vaidya, 2016), are focused on the observable behavior of the individual organism (Donahoe, 2017; Schlinger, 2015), and rigorous investigations utilizing single-subject design may be conducted (Soto, 2020). Although some barriers to collaboration exist (Ortu & Vaidya, 2016) incorporating neuroscience findings into behavior analysis may be necessary for the overall future of the field (Fox, 2018).

A significant portion of important human activity is largely unseen but remains within the domain of behavior analysis. As behavior analysts attempt to influence private behavior, the environment–behavior framework should be retained. It is therefore insufficient to simply refer to all unseen events as "private events" without further distinguishing behavior from the environment. We propose a neurobiological-behavioral approach that builds upon the arguments and lines of reasoning offered by others (e.g., Donahoe, 2017; Donahoe & Palmer, 2004; Palmer, 2009; Thompson, 2007). This approach not only furthers possible collaboration between behavior analysis and disciplines such as neuroscience, but also helps ensure that as our discipline walks boldly into the analysis of private behavior, we do so on sure footing.

A Neurobiological-Behavioral Approach

Private behaviors are anything an organism does that, at least momentarily, are detectable to only that organism. Private stimuli include neurobiological stimuli that, at least momentarily, are detectable only to that organism and are distinct from behavior—public or private. To the extent that an organism's biology (or novel technologies) may allow for the detection of private stimuli, these stimuli may enter into a functional relation with behavior. From the organism's perspective, a nondetected event is not a stimulus. The biological capacity to detect a stimulus, and what is described as "being aware" of a private stimulus (e.g., tacting private stimuli), are distinct. The capacity to detect a stimulus may, however, be a requisite to "awareness." An organism need not be "aware" of a stimulus for it to have an effect. Neurobiological stimuli include the commonly understood vestibular, proprioceptive, and interoceptive stimuli, but may also include any other stimuli in the body such as chemical (e.g., hormones or neurotransmitters) and electrical signals.

If an event is detectable by only the organism and is not more behavior of the organism it is considered a private stimulus. For example, the secretion of adrenaline by the suprarenal glands is private behavior. The adrenaline flowing through the body in some detectable way is a private stimulus. The actions of a neuron (e.g., gate opening) are private behavior. The resulting voltage-change and electrical transmission is a private stimulus. These private behaviors and private stimuli are conceptualized as an unending stream of constant interaction—private behaviors can alter neurobiological contexts, and this new context can set the stage for future private behavior. At a fundamental level, this unending stream of interaction is the same as that inherent to any analysis of public behavior. The organism is *always* interacting with the environment and this interaction is *always* changing the environment in ways that may influence future interaction.

Neural activity and biological systems are both involved in the acquisition and emission of behaviors (Thompson, 2007). Biological systems influence behavior (e.g., hormonal levels may influence the value of reinforcers) and the experiences of the organism influence the biological system (i.e., developmental plasticity; Lea et al., 2017). Although neural stimulation may evoke behavior, other biological stimulation is also part of the overall context. Further, neural activity is malleable and may be conditioned like other behavior (e.g., Schultz, 2007; Sommer & Schweinberger, 1992).

The term *neurobiological-behavioral* is suggested as this enhances the precision of the analysis. This term separates the currently ambiguous term private events into private stimuli (neurobiological stimuli) and private behaviors, which is necessary for any behavioral analysis. Further, the term "neurobiological" does not suggest a specific private stimulus or stimulus location. The private contextual stimuli are not simply neurotransmitters, nor do they reside only in a specific area. A thought does not reside in the brain, nor do the private contextual stimuli in a functional relation with that thought. The neurobiological stimuli include the overall context of interoceptive, chemical, hormonal, and electrical signals which are detectable by the organism and thus may enter into a functional relation given a sufficient learning history.

An Application Example

When the neurobiological-behavioral approach is applied to the previous example of thinking about dogs and being anxious, the clarifying nature and greater precision of this approach become more apparent. Imagine again that a child is bit by a dog at a young age and now reports becoming anxious when seeing, hearing about, or thinking about dogs. The dog bite was a painful, distressing, and aversive event. Any stimuli occurring at the time of the bite may become associated with the event, acquire aversive properties, and come to produce similar distress. This includes the street where the bite occurred, the dog itself, the sounds of barking, and the neurobiological stimuli present in the body when the child was bit (e.g., blood pressure, adrenaline, cortisol, dog evoked-potentials and event-related potentials). To the extent the presence of these neurobiological stimuli is detectable and can be responded to, they may acquire functions via processes such as stimulus–stimulus pairing and transformation of stimulus function. This is consistent with conditioning of any public stimuli occurring at the time of the bite, such as the dog or street. In the future, this newly conditioned neurobiological context may now elicit anxiety just as would a physical dog. It is important to note that this context may be produced by myriad behaviors such as seeing the street, hearing the word dog, or privately thinking about a dog.

The distinction between the two explanations—(1) anxiety is caused by the thought of a dog (behavior–behavior relation); and (2) neurobiological stimuli were conditioned to elicit anxiety (environment–behavior relation)—is not merely semantic or linguistic. In the neurobiological-behavioral account, the thought of a dog (private behavior) altered the overall environmental context. One aspect of this alteration was to directly produce neurobiological stimuli (private stimuli) that functioned to evoke distress (private and public behavior). Contrary to the behavior–behavior relation, the neurobiological-behavioral explanation could be experimentally confirmed with sufficient technology. The neurobiological stimuli associated with the thought "dog" could be identified as they should be consistently produced by the response. A functional analysis of these stimuli and anxiety behavior could then be conducted. If a relation was confirmed, this could be acted upon in a variety of ways such as counterconditioning (Keller et al., 2020) or direct inhibition of the neural activity that produced the neurobiological stimuli. Although this account of anxiety is greatly simplified, it demonstrates how firmly adhering to an environment-behavior analysis may lead to direct prediction and influence.

Particularly with advances in neuroscience applications, we are approaching a time when the direct influence of private events is possible. Optogenetics is an emerging area of research that combines both optics and genetics to enable the optical control of specific action potentials within freely moving organisms (Yizhar et al., 2011). In optogenetics, neurons are genetically altered by introducing proteins into the neuron cells. These proteins, called Opsins, have light-gated ion channels, and a directed pulse of light can evoke neural firing that allows for direct manipulation of the neural activity (Fenno et al., 2011). This, in turn, affords an analysis of the relation between specific neural stimuli and behavior. For example, van der Zouwen et al., (2021) used optogenetics to induce locomotion in mice, and could even increase the speed of locomotion by increasing light power.

From a neuroscience perspective, uncovering the interaction of highly specific brain area stimulation with behavior enables a deeper understanding of the overall neural system, structure, and function. From a behavioral perspective, however, the prospect of functional analysis and influence of private behavior is of great importance. Thinking is behavior and is evoked by neurobiological and public contextual stimuli. Whereas behavior analysis has largely manipulated public stimuli in functional analyses of public behavior, neuroscience technologies such as optogenetics may enable manipulation of neurobiological stimuli, and the functional analysis of private behaviors.

The neurobiological–behavioral approach is consistent with the conventional environment–behavior analysis and interventions currently in use with public behavior. It is the same analysis on a more molecular level. Any living organism is in a constant sequence of reciprocal interactions with the environment. Behaviors change the environment and are, in turn, influenced by the environment; this is true at the level of private behavior just as much as public behavior. Intervening on a neurobiological level may be considered merely "skipping steps" in the sequence. Rather than present a public stimulus that, through a sequence of public/private stimulus–response events, ultimately produces specific neurobiological stimulation which evokes a specific thought, it may be possible to "skip" directly to the neurobiological stimulation. A thought may be produced by directly producing the neurobiological context of which the thought is a function. The environment–behavior approach is conceptually preserved, but the avenues of assessment and intervention are expanded.

Strengths of a Neurobiological-Behavioral Approach

Explanations of behavior are ideally significant in scope, precision, and depth. An analysis should have a broad degree of scope by applying to a range of cases, have high precision by incorporating as few analytic concepts as possible, and have depth by extending across other well-established scientific domains (Hayes et al., 2012). Although the general concept of private events has been pragmatic and enabled some discussion of events that have an audience of one, the term is not a technical one and does not possess high scope, precision, or depth (though some exist). This may partially underlie some of the challenges behavior analysis has had incorporating these events into the overall analysis of behavior. As suggested by Hayes et al. (2012) vague terms must ultimately "be anchored gradually to more technical accounts" and there exists an "*a priori* goal of analyses with precision, scope, and depth" (p. 7). The neurobiological–behavior approach may be considered an analysis that possesses this scope, precision, and depth. The approach has high scope in that it inherently treats all private stimuli similarly regardless of associated behavior rather than focusing exclusively on neural stimulation. The approach has high precision in that the nature of a private stimulus is clarified as a nonbehavior neurobiological event, rather than more behavior. Further, no additional analytic concepts are necessary in the approach. Finally, by eliminating behavior–behavior relations in explanations of private events, and situating private stimuli as neurobiological events, cohesion and collaboration with other disciplines are improved, which increases overall depth.

A neurobiological–behavioral approach may improve the analysis and treatment of behavior by clarifying the distinction and interaction between private stimuli and private behavior. An example might again be in the treatment of anxiety. One common intervention is systematic desensitization wherein a person is repeatedly and systematically exposed to the anxiety provoking stimuli (Head & Gross, 2009). Although most agree private responding occurs during the exposure, it is often assumed that a reduction of the public responses will also reduce associated private responses (Friman et al., 1998). By identifying neurobiological stimuli (e.g., event-related potentials) and private responses associated with public anxiety behavior, practitioners may target a range of members of the "anxiety" response class, such as private biased attending to anxiety evoking stimuli (Carlson, 2021; Gupta et al., 2019). Future anxiety may be mitigated by counterconditioning or teaching someone how to respond to neurobiological stimuli associated with anxiety. Further, advances in neuroscience and the neurobiological–behavioral approach could allow for more nuanced or detailed measurement. In addition to measuring large-scale anxiety behaviors such as running away, and mid-level behaviors such as heart rate, reductions in neural responses to anxiety provoking stimuli could also be measured.

A neurobiological–behavioral approach may also result in a more thorough analysis of current behavior analytic concepts such as motivating operations. At present, motivating operations are largely identified through knowledge of extended environmental–behavior events (e.g., when did the person last eat; what was said to them earlier in the day). However, there are likely correlated neurobiological stimuli occurring in the moment that may be available for analysis to suggest or confirm current motivational effects. For example, if someone has not eaten in a day there are likely establishing and evocative effects related to food and food-producing behavior. This may be identified through knowledge of the timing of the last food consumption. It may also be determined by measuring neurobiological stimuli associated with the private response of "hunger," such as a collapsed stomach, low blood glucose levels, the presence of the digestive enzyme alpha-amylase, a headache, or the hormone ghrelin. Blood glucose levels, for example, are considered a reliable biomarker of hunger, and decreases in blood glucose often precede increases in behaviors such as requesting food and subjective reports of hunger (Campfield et al., 1996). As an alternative, reports of satiation tend to fluctuate with levels of salivary alpha-amylase (an enzyme that begins food digestion) indicating the detection of this enzyme may provide information on levels of satiation (Harthoorn, 2008). Further, salivary alpha-amylase also appears associated with food preferences (Tarragon et al., 2018), so detection may also suggest which types of foods will function as potent reinforcers. Both blood glucose and salivary alpha-amylase can be inexpensively, simply, and quickly measured in real time with a blood sugar monitor or colorimetric enzyme assay. Although perhaps unnecessary for general practitioner use, this information may be useful in situations where more precise levels of motivation were sought, where the food-consumption history of the organism was unknown, or to determine whether food presentation functioned as an abolishing operation.

It is important to note that levels of blood glucose and salivary alpha-amylase do not guarantee the presence or absence of a food-related motivating operation. A person's hunger response to blood glucose levels may be conditioned and is at least partly influenced by their learning history (Ciampolini & Bianchi, 2006; Stevenson et al., 2023). Further, a stronger relation between levels of salivary alpha-amylase and levels of hunger is found in overweight individuals relative to those with average weight (Moreno-Padilla et al., 2020), which may also indicate some conditioning effect. These findings are consistent with neurobiological-behavioral approach predictions and highlight the reciprocal nature of behavior and neurobiological contexts and the importance of individual functional analysis.

Acquired Stimulus Functions

Neurobiological events can acquire a variety of stimulus functions. As antecedent stimuli, these events may acquire eliciting effects, discriminative effects, or function as motivating operations. For example, if someone thinks about biting into a sour lemon, this may alter the context by producing neurobiological stimuli that are in a functional relation with salivation. In theory, any response that produces a similar neurobiological context may also elicit salivation. Skinner suggests something similar regarding anxiety when he notes that if public stimulation can produce anxiety, it would be possible for any bodily condition (i.e., neurobiological context) to be conditioned to also elicit anxiety at a later point. "The condition felt as anxiety begins to act as a second conditioned aversive stimulus" (Skinner, 1989, p. 7).

Discriminative effects of private stimuli have been documented, such as in drug discrimination (e.g., Kangas & Maguire, 2016). In a typical drug discrimination procedure rats may be trained to differentially respond to one of two levers based on the interoceptive stimulation produced by a drug. For example, rats may be provided fentanyl prior to some training sessions, and responding to one lever (drug lever) is reinforced with food. Prior to other training sessions, rats may be provided a saline solution and responding to a different lever (saline lever) is also reinforced with food. After sufficient training, the rats learn to discriminate between levers depending on whether fentanyl was previously delivered or not. In such a situation it would appear the private interoceptive stimulation provided by the fentanyl acquired discriminative properties related to lever pressing. Further, as might be expected, the discriminative function of the private stimulation may generalize across other narcotics (Kangas & Maguire, 2016). Humans, for their part, can learn to discriminate between drug and placebo conditions, and between different drugs based on the subjective experience associated with the drug (Stoops, 2022). For example, if someone is given either cocaine or a placebo, they can accurately discriminate at a later point whether they are under the influence of cocaine or not. Everyday examples abound as, for example, a person simply stating, "I feel sick" based on the subjective experience of nausea.

Finally, there is reason to believe that neurobiological events can function as motivating operations. For example, if a hungry person for whatever reason imagines their food covered in flies and feces, the neurobiological stimuli produced by this private behavior may function as an abolishing operation and result in a decrease in both the value of the food and the likelihood of eating. Although these effects are not *entirely* due to the neurobiological stimuli, those stimuli are an important part of the overall context in which the effects occur.

A consideration of the neurobiological stimuli functioning as motivating operations may be critical for individuals with genetic disorders such as Prader-Willi syndrome. Prader-Willi affects multiple biological systems (Driscoll et al., 2023) and is associated with a variety of physiological and behavioral characteristics, including extreme overeating. In individuals with Prader-Willi syndrome, the consumption of food does not appear to act as an abolishing operation; instead, the establishing effect for food is nearly always present. This appears partly related to the genetic disorder's impact on the hypothalamus (among other physiological systems), which releases hormones including those that regulate feeling full (Driscoll et al., 2023). These neurobiological stimuli can act as motivating operations that influence other behaviors that have produced access to food in the past, such as pica, food stealing, or aggression. Attempts to assess and treat these behaviors in an individual with Prader-Willi may be furthered by a more complete consideration of neurobiological stimuli.

Neurobiological stimuli may also function as consequences and can potentially exert either reinforcing or punishing effects. The consumption of narcotics, for example, induces a neurobiological context that may subjectively be referred to as "feeling high." Depending on the neurobiological stimulation produced by the drug, these sensations may alter the future frequency of drug consumption. A "pleasant high" may result in future drug use, whereas an "unpleasant high" may decrease drug use. As an alternative, if a person has a headache and takes ibuprofen, the resulting change in neurobiological context may result in someone saying their headache is gone, and the person may be more likely to take ibuprofen in the future. Direct influence of these neurobiological contexts as reinforcers is also possible. For example, Witten et al. (2011) provided rats with optogenetic enhancements and placed the rats in chambers with two identical nosepoke ports. Responding to one port was differentially reinforced on a fixed-ratio 1 schedule via direct, internal, optogenetic (light-pulse) activation of the dopaminergic system. No other differential consequences were provided. During training, responding increased towards the lever associated with dopamine-mediated positive reinforcement. This responding decreased during extinction trials and again increased during a reacquisition phase. Advances in our understanding of the involvement of dopaminergic systems in the process of reinforcement afford more complete explanations regarding how predicted, unpredicted, and omitted reinforcer delivery differentially affects responding (Schultz, 2007).

It is important to note that verbal behavior may play an influential role in the overall understanding of neurobiological contextual influence. The neurobiological-behavioral approach suggests that both public and private verbal behavior can produce changes to the environment (public and/or private) that may acquire stimulus functions. With public verbal behavior, for example, a person may say something aloud that produces physical vibrations to which another person may respond. Part of responding to these physical vibrations inevitably produces neurobiological contexts as part of the overall sequence of events described as "hearing." Private verbal behavior, on the other hand, does not produce physical vibrations. Provided the content of the speech is similar, however, and given a sufficient verbal history, the private verbal behavior would be expected to produce neurobiological contexts that are like those produced when hearing words spoken aloud. Thus, verbal behavior, whether spoken privately or publicly, could produce similar neurobiological contexts that may evoke similar responding.

A Continuum of Private–Public Contextual Influence

In the end, behavior is always partly a function of current contextual events. This includes both private and public stimuli, which together represent 100% of an organism's context. Recognizing the functional effect of private stimuli does not mean that behavior occurs independently of the public environment. Neurobiological stimuli are merely a *part* of an organism's overall environment, which also includes public stimuli. The neurobiological-behavioral approach does not give way to mentalistic explanations of behavior, nor does it simply reduce behavior to neural or biological functioning. Including neurobiological stimuli simply provides for a more complete functional analysis of behavior. The neurobiological-behavioral approach does, however, suggest that the contributive contextual effects of private and public stimuli are not static—contextual influence can and does shift, and at any given moment the influence of private stimulation on a given behavior may be more or less than that of public stimulation. This shifting contextual influence may be capitalized upon to exert desired behavioral influence.

If, for example, a person wanted to engage in a private brainstorming activity, they might find it advantageous to increase the contextual influence of private stimulation. This might be accomplished by actively trying to decrease public environmental influence such as by turning off music with spoken words, closing their eyes, or removing distracting sights and sounds. As the influence of public and private contexts always combines to 100% of the organism's context, decreasing the relative influence of the public environment could increase the influence of the private environment. On the other hand, a person attempting to "be more mindful and focused on the moment" might find it advantageous to decrease overall private contextual influence. Acceptance and commitment therapy often incorporates just such mindfulness activities when teaching people to respond to current contingencies (Hayes, 2016). The goal might be to decrease private contextual influence to increase public contextual influence—the present moment. The combined influence of both public and private contexts is always 100%, but at times it may be advantageous to adjust the ratio.

Advances in Technologies: Neuroscience and Brain–Computer Interfaces

Advances in behavioral neuroscience (Ortu & Vaidya, 2016) allow measurement and analysis of brain activity down to the level of a single neuron. These analyses allow for both the prediction and influence of precise neural activity, and experimental analysis offers support for behavioral interpretations of private events. For example, whereas private behaviors such as listening or auditory imagining were once inferred, there is growing support for their existence as observable instances of subvocal behavior (Schlinger, 2008, 2009). Further, behavioral explanations of "remembering" have been supported at the neural level with advances in the understanding of feedback systems in the prefrontal cortex (Donahoe, 2017).

A neuron is a specialized cell that can transmit information in the form of electrical and chemical signals to other cells. In a resting neuron, a voltage-gate maintains a negative charge. When a stimulus evokes a response, at a neural level there is a rapid change in voltage along the neuron's membrane. Positively charged ions rush into the membrane causing depolarization and repolarization that propagates down the length of the axon. This is known as an action potential and plays a critical role in overall organism functioning. From a neurobiological-behavioral perspective, the actions of the neuron (e.g., opening and closing of voltage gates) may be considered behavior, whereas the positively and negatively charged ions (e.g., sodium, potassium, chloride) and the overall voltage, may be considered stimuli.

These observations have enabled once private stimuli and behaviors to affect the public world via brain–computer interfaces (BCIs). BCIs harness neural activity to effectively control the actions of external devices (e.g., a robotic arm). Research on BCIs began with animal trials as early as the 1960s and moved to human trials soon thereafter (Shih et al., 2012). In an early demonstration, Elbert et al. (1980) showed that providing a person with biofeedback on their neural activity (slow cortical potentials) enabled the person to change those potentials to control the movements of a digital rocket on a television screen. BCIs allow a person to privately respond (e.g., "think" about moving their arm) and thereby cause events in the environment outside of the skin (e.g., control the movements of a robotic arm). Further, like any public behavior, there is a reciprocal effect as these environmental actions can have a selecting effect on the private responding. Private responses that more effectively control the robotic arm are more likely to occur again.

Although BCI technology is still in development and not widely available, there are a range of foreseeable applications. In medical fields, BCIs can enable a person to effectively communicate with the world in ways that do not rely on typical neuromuscular pathways. This holds significant promise for individuals with severe motor disabilities or neuromuscular diseases or injuries (Mak & Wolpaw, 2009), and may enable independence in a variety of ways ranging from controlling robotic prostheses (Hochberg et al., 2012) to synthesizing speech from neural signals (Pandarinath

& Ali, 2019). Commercial applications also exist such as BCI-enabled videogames or industrial uses. Finally, BCIs may enable the expansion of the range of available senses. Hartmann et al. (2016), for example, embedded a microstimulation-based neuroprosthesis into the brains of rats, which effectively enabled infrared light to stimulate whisker neurons in the somatosensory cortex. Following training, the rats were able to navigate an infrared environment to locate water reinforcement. Given that rats have no evolutionary history of sensing infrared light, these findings demonstrate possible applications of BCIs as well as the surprising malleability of sensory systems and the selection of new responses to private stimulation.

As noted by Skinner (1953, p. 282) "the line between public and private is not fixed. The boundary shifts with every discovery of a technique making private events public." Previously private responding (e.g., actions of the neuron) and previously private stimulation (e.g., voltage changes) have become public events, at least when observed. The resulting technologies and applications demonstrate the importance of understanding the entire context within which an organism responds.

Skinner suggests, "a behavioral analysis has two necessary but unfortunate gaps—the spatial gap between behavior and the variables of which it is a function and the temporal gap between the actions performed upon an organism and the often-deferred changes in its behavior. These gaps can be filled only by neuroscience, and the sooner they are filled, the better" (Skinner, 1988, p. 470). Some of these gaps are now closing, and fields are merging.

Conclusion

The range of neurobiological stimuli that may influence behavior is unknown. Just as some stimuli in a public context may be irrelevant to a particular behavior, so may some neurobiological stimuli. Other disciplines, such as biology and neuroscience, may help clarify this to further enhance the overall analysis of behavior. Given that a neurobiological event is a physical and directly manipulable one, a neurobiological-behavior analysis is a verifiable hypothesis. As Skinner (1984) notes, "whenever it becomes possible to say what conditions within the organism influence the response 'I am depressed,' for example, and to produce these conditions at will, a degree of influence and prediction characteristic of responses to external stimuli will be made possible" (p. 548). To determine whether some neurobiological context was in a functional relation with a behavior, one could systematically induce the neurobiological context to confirm (Soto, 2020).

Skinner (1999) suggests, "a comprehensive set of causal relations stated with the greatest possible precision is the best contribution which we, as students of behavior, can make in the co-operative venture of giving a full account of the organism as a biological system" (p. 316). The neurobiological-behavioral account is a step in this direction, and advances in technology are making finer-grained analyses possible. It is assuredly not necessary to analyze all behavior through a neurobiological-behavioral lens. Radical behaviorism has squarely adopted a pragmatic approach to science—the truth of any theory lies in its usefulness in accomplishing the goals of the science (Moore, 2008). Our goals are the prediction and influence of behavior (Skinner, 1953). There may be times when a molar analysis allows us to better achieve these outcomes (Baum, 2011). At other times, however, such as in the case of predicting and influencing private behaviors, a more focused neurobiological-behavioral approach may prove more suitable. In both situations, however, the analysis must include both the organism and the nonbehavior environment. A neurobiological-behavioral approach conforms with current analytic tradition, reduces behavior–behavior explanations, and provides greater clarity to the nature, influence, and interaction of private behaviors and private stimuli.

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References

Anderson, C. M., Hawkins, R. P., & Scotti, J. R. (1997). Private events in behavior analysis: Conceptual basis and clinical relevance. *Behavior Therapy, 28*, 157–179. https://doi.org/10.1016/S0005-7894(97)80040-8

Anderson, C. M., Hawkins, R. P., Freeman, K. A., & Scotti, J. R. (2000). Private events: Do they belong in a science of human behavior? *The Behavior Analyst, 23*(1), 1–10. https://doi.org/10.1007/BF03391995

Axe, J. B., Phelan, S. H., & Irwin, C. L. (2018). Empirical evaluations of Skinner's analysis of problem solving. *Analysis of Verbal Behavior, 35*(1), 39–56. https://doi.org/10.1007/s40616-018-0103-4

Baum, W. M. (2011). No need for private events in a science of behavior: Response to commentaries. *The Behavior Analyst, 34*, 237–244. https://doi.org/10.1007/BF03392255

Boring, E. G., Bridgman, P. W., Feigl, H., Pratt, C. C., & Skinner, B. F. (1945). Rejoinders and second thoughts. *Psychological Review, 52*(5), 278–294. https://doi.org/10.1037/h0063275

Campfield, L. A., Smith, F. J., Rosenbaum, M., & Hirsch, J. (1996). Human eating: Evidence for a physiological basis using a modified paradigm. *Neuroscience & Biobehavioral Reviews, 20*(1), 133–1137. https://doi.org/10.1016/0149-7634(95)00043-E

Carlson, J. M. (2021). A systematic review of event-related potentials as outcome measures of attention bias modification. *Psychophysiology, 58*(6), e13801. https://doi.org/10.1111/psyp.13801

Ciampolini, M., & Bianchi, R. (2006). Training to estimate blood glucose and to form associations with initial hunger. *Nutrition & Metabolism, 3*, 42. https://doi.org/10.1186/1743-7075-3-42

Czeisler, C. A. (2013). Perspective: Casting light on sleep deficiency. *Nature, 497*(7450), S13. https://doi.org/10.1038/497S13a

Delprato, D. J., & Midgley, B. D. (1992). Some fundamentals of B. *F. Skinner's behaviorism. American Psychologist, 47*, 1507–1520. https://doi.org/10.1037/0003-066X.47.11.1507

Donahoe, J. W. (2017). Behavior analysis and neuroscience: Complementary disciplines. *Journal of the Experimental Analysis of Behavior, 107*(3), 301–320. https://doi.org/10.1002/jeab.251

Donahoe, J. W., & Palmer, D. C. (2004). *Learning and complex behavior*. Allyn & Bacon.

Driscoll, D. J., Miller, J. L., & Cassidy, S. B. (2023). *GeneReviews*: Prader-Willi Syndrome https://www.ncbi.nlm.nih.gov/books/NBK1330/.

Dymond, S., Bennett, M., Boyle, S., Roche, B., & Schlund, M. (2017). Related to anxiety: Arbitrarily applicable relational responding and experimental psychopathology research on fear and avoidance. *Perspectives on Behavior Science, 41*(1), 189–213. https://doi.org/10.1007/s40614-017-0133-6

Elbert, T., Rockstroh, B., Lutzenberger, W., & Birbaumer, N. (1980). Biofeedback of slow cortical potentials. *I. Electroencephalography & Clinical Neurophysiology, 48*(3), 293–301. https://doi.org/10.1016/0013-4694(80)90265-5

Fenno, L., Yizhar, O., & Deisseroth, K. (2011). The development and application of optogenetics. *Annual Review of Neuroscience, 34*, 389–412. https://doi.org/10.1146/annurev-neuro-061010-113817

Fox, A. E. (2018). The future is upon us. *Behavior Analysis: Research & Practice, 18*(2), 144–150. https://doi.org/10.1037/bar0000106

Friman, P. C., Hayes, S. C., & Wilson, K. G. (1998). Why behavior analysts should study emotion: The example of anxiety. *Journal of Applied Behavior Analysis, 31*(1), 137–156. https://doi.org/10.1901/jaba.1998.31-137

Gupta, R. S., Kujawa, A., & Vago, D. R. (2019). The neural chronometry of threat-related attentional bias: Event-related potential (ERP) evidence for early and late stages of selective attentional processing. *International Journal of Psychophysiology, 146*, 20–42. https://doi.org/10.1016/j.ijpsycho.2019.08.006

Harthoorn, L. F. (2008). Salivary α-amylase: A measure associated with satiety and subsequent food intake in humans. *International Dairy Journal, 18*, 879–883. https://doi.org/10.1016/j.idairyj.2007.11.006

Hartmann, K., Thomson, E. E., Zea, I., Yun, R., Mullen, P., Canarick, J., Huh, A., & Nicolelis, M. A. (2016). Embedding a panoramic representation of infrared light in the adult rat somatosensory cortex through a sensory neuroprosthesis. *Journal of Neuroscience: The Official Journal of the Society for Neuroscience, 36*(8), 2406–2424. https://doi.org/10.1523/JNEUROSCI.3285-15.2016

Hayes, S. C. (2016). Acceptance and commitment therapy, relational frame theory, and the third wave of behavioral and cognitive therapies. *Behavior Therapy, 47*(6), 869–885. https://doi.org/10.1016/j.beth.2016.11.006

Hayes, S. C., & Brownstein, A. J. (1986). Mentalism, behavior-behavior relations, and a behavior-analytic view on the purposes of science. *The Behavior Analyst, 9*, 175–190. https://doi.org/10.1007/BF03391944

Hayes, S. C., Hayes, L. J., & Reese, H. W. (1988). Finding the philosophical core: A review of Stephen C. Pepper's world hypothesis: A study in evidence. *Journal of the Experimental Analysis of Behavior, 50*, 97–111. https://doi.org/10.1901/jeab.1988.50-97

Hayes, S. C., Barnes-Holmes, D., & Wilson, K. G. (2012). Contextual behavioral science: Creating a science more adequate to the challenge of the human condition. *Journal of Contextual Behavioral Science, 1*(1–2), 1–16. https://doi.org/10.1016/j.jcbs.2012.09.004

Head, L. S., & Gross, A. M. (2009). Systematic desensitization. In W. T. O'Donohue & J. E. Fisher (Eds.), *General principles and empirically supported techniques of cognitive behavior therapy* (pp. 640–647). John Wiley & Sons.

Heward, W. L., Critchfield, T. S., Reed, D. D., Detrich, R., & Kimball, J. W. (2022). ABA from a to Z: Behavior science applied to 350 domains of socially significant behavior. *Perspectives on Behavioral Science, 45*, 327–359. https://doi.org/10.1007/s40614-022-00336-z

Hochberg, L. R., Bacher, D., Jarosiewicz, B., Masse, N. Y., Simeral, J. D., Vogel, J., Haddadin, S., Liu, J., Cash, S. S., van der Smagt, P., & Donoghue, J. P. (2012). Reach and grasp by people with tetraplegia using a neurally controlled robotic arm. *Nature, 485*(7398), 372–375.

Johnston, J. M., & Pennypacker, H. S. (1980). Subject matter of the science of behavior. In J. Johnston (Ed.), *Strategies and tactics of human behavioral research* (p. 48). Lawrence Erlbaum Associates.

Kangas, B. D., & Maguire, D. R. (2016). Drug discrimination and the analysis of private events. *Behavior Analysis: Research & Practice, 16*, 159–168. https://doi.org/10.1037/bar0000032

Kantor, J. R., & Smith, N. W. (1975). The reaction system. In J. R. Kantor & N. W. Smith (Eds.), *The science of psychology: An interbehavioral survey* (pp. 47–55). Principia.

Keller, N. E., Hennings, A. C., & Dunsmoor, J. E. (2020). Behavioral and neural processes in counterconditioning: Past and future directions. *Behaviour Research and Therapy, 125*, 103532. https://doi.org/10.1016/j.brat.2019.103532

Kelly, A. D., & Kelly, M. E. (2021). Acceptance and commitment training in applied behavior analysis: Where have you been all my life? *Behavior Analysis Practice, 15*, 43–54. https://doi.org/10.1007/s40617-021-00587-3

Lea, A. J., Tung, J., Archie, E. A., & Alberts, & Alberts, S. C. (2017). Developmental plasticity: Bridging research in evolution and human health. *Evolution, Medicine, & Public Health, 2017*, 162–175. https://doi.org/10.1093/emph/eox019

Mak, J. N., & Wolpaw, J. R. (2009). Clinical applications of brain-computer interfaces: Current state and future prospects. *IEEE Reviews in Biomedical Engineering, 2*, 187–199. https://doi.org/10.1109/RBME.2009.2035356

Mandavia, A., Masuda, A., Moore, M., Mendoza, H., Donati, M. R., & Cohen, L. L. (2015). The application of a cognitive defusion technique to negative body image thoughts: A preliminary analogue investigation. *Journal of Contextual Behavioral Science, 4*(2), 86–95. https://doi.org/10.1016/j.jcbs.2015.02.003

Marr, M. J. (2009). The natural selection: Behavior analysis as a natural science. *European Journal of Behavior Analysis, 10*, 105–120. https://doi.org/10.1080/15021149.2009.11434313

Moore, J. (2008). Conceptual foundations of radical behaviorism. *Sloan.*

Moore, K., Bullard, A., Sweetman, G., & Ahearn, W. H. (2022). Assessing and treating anxiety in individuals with autism. *Behavior Modification, 46*(6), 1279–1313. https://doi.org/10.1177/01454455211051678

Moreno-Padilla, M., Maldonado-Montero, E. F., Enguix-Armada, A., & Reyes del Paso, G. A. (2020). Salivary alpha-amylase mediates the increase in hunger levels in adolescents with excess weight after viewing food images. *Childhood Obesity, 16,* 53–58. http://doi.org/https://doi.org/10.1089/chi.2019.0133

Morris, E. K. (1993). Behavior analysis and mechanism: One is not the other. *The Behavior Analyst, 16*, 25–43. https://doi.org/10.1007/BF03392606

Moxley, R. A. (1992). From mechanistic to functional behaviorism. *American Psychologist, 47*(11), 1300–1311. https://doi.org/10.1037/0003-066X.47.11.1300

Ortu, D. (2012). Neuroscientific measures of covert behavior. *The Behavior Analyst, 35*(1), 75–87. https://doi.org/10.1007/BF03392267

Ortu, D., & Vaidya, M. (2016). The challenges of integrating behavioral and neural data: Bridging and breaking boundaries across levels of analysis. *The Behavior Analyst, 40*(1), 209–224. https://doi.org/10.1007/s40614-016-0074-5

Palmer, D. C. (2009). The role of private events in the interpretation of complex behavior. *Behavior and Philosophy, 37*, 3–19 http://www.jstor.org/stable/41472419

Palmer, D. (2011). Consideration of private events is required in a comprehensive science of behavior. *The Behavior Analyst, 34*, 201–207. https://doi.org/10.1007/BF03392250

Pandarinath, C., & Ali, Y. H. (2019). Brain implants that let you speak your mind. *Nature, 568*, 466–467. https://doi.org/10.1038/d41586-019-01181-y

Schlinger, H. D. (2008). Conditioning the behavior of the listener. *International Journal of Psychology & Psychotherapy, 8*, 309–322.

Schlinger, H. D. (2009). Auditory imagining. *European Journal of Behavior Analysis, 10*(1), 77–85. https://doi.org/10.1080/15021149.2009.11434310

Schlinger, H. D. (2011). Introduction: Private events in a natural science of behavior. *The Behavior Analyst, 34*(2), 181–184. https://doi.org/10.1007/BF03392248

Schlinger, H. D. (2015). Behavior analysis and behavioral neuroscience. *Frontiers in Human Neuroscience, 9*, 210. https://doi.org/10.3389/fnhum.2015.00210

Schnaitter, R. (1975). Between organism and environment. A review of B. F. Skinner's *about behaviorism*. *Journal of the Experimental Analysis of Behavior, 23*, 297–307. https://doi.org/10.1901/jeab.1975.23-297

Schultz, W. (2007). Behavioral dopamine signals. *Trends in Neurosciences, 30*(5), 203–210. https://doi.org/10.1016/j.tins.2007.03.007

Schwartz, W. J., & Klerman, E. B. (2019). Circadian neurobiology and the physiologic regulation of sleep and wakefulness. *Neurologic Clinics, 37*(3), 475–486. https://doi.org/10.1016/j.ncl.2019.03.001

Shih, J. J., Krusienski, D. J., & Wolpaw, J. R. (2012). Brain-computer interfaces in medicine. *Mayo Clinic Proceedings, 87*, 268–279. https://doi.org/10.1016/j.mayocp.2011.12.008

Skinner, B. F. (1953). *Science and human behavior*. Macmillan.

Skinner, B. F. (1957). Verbal behavior. *Appleton-Century-Crofts.* https://doi.org/10.1037/11256-000

Skinner, B. F. (1968). *The technology of teaching*. Appleton-Century-Crofts.

Skinner, B. F. (1969). Behaviorism at fifty. In *Contingencies of reinforcement: A theoretical analysis* (pp. 221–268). Appleton-Century-Crofts.

Skinner, B. F. (1974). *About behaviorism*. Random House.

Skinner, B. F. (1984). The operational analysis of psychological terms. *Behavioral & Brain Sciences, 7*, 547–581. https://doi.org/10.1037/h0062535

Skinner, B. F. (1988). Comments and consequences. In A. C. Catania & S. Harnad (Eds.), *The selection of behavior: The operant behaviorism of B. F. Skinner* (pp. 382–461). Cambridge University Press.
Skinner, B. F. (1989). *Recent issues in the analysis of behavior*. Prentice Hall.
Skinner, B. F. (1999). *What is psychotic behavior?* In *Cumulative record: Definitive edition.* Copley Publishing Group.
Sommer, W., & Schweinberger, S. (1992). Operant conditioning of P300. *Biological Psychology, 33*(1), 37–49. https://doi.org/10.1016/0301-0511(92)90004-e
Soto, P. L. (2020). Single-case experimental designs for behavioral neuroscience. *Journal of the Experimental Analysis of Behavior, 114*, 447–467. https://doi.org/10.1002/jeab.633
Stevenson, R. J., Bartlett, J., Wright, M., Hughes, A., Hill, B. J., Saluja, S., & Francis, H. M. (2023). The development of interoceptive hunger signals. *Developmental Psychobiology, 65*(2), e22374. https://doi.org/10.1002/dev.22374
Stoops, W. W. (2022). A brief introduction to human behavioral pharmacology: Methods, design considerations and ethics. *Perspectives on Behavior Science, 45*(2), 361–381. https://doi.org/10.1007/s40614-022-00330-5
Tarragon, E., Stein, J., & Meyer, J. (2018). Basal levels of salivary alpha-amylase are associated with preference for foods high in sugar and anthropometric markers of cardiovascular risk. *Behavioral Sciences, 8*(10), 94. https://doi.org/10.3390/bs8100094
Thompson, T. (2007). Relations among functional systems in behavior analysis. *Journal of the Experimental Analysis of Behavior, 87*(3), 423–440. https://doi.org/10.1901/jeab.2007.21-06
van der Zouwen, C. I., Boutin, J., Fougère, M., Flaive, A., Vivancos, M., Santuz, A., Akay, T., Sarret, P., & Ryczko, D. (2021). Freely behaving mice can brake and turn during optogenetic stimulation of the mesencephalic locomotor region. *Frontiers in Neural Circuits, 15*, 639900. https://doi.org/10.3389/fncir.2021.639900
Watson, J. B. (1913). Psychology as the behaviorist views it. *Psychological Review, 20*, 158–177. https://doi.org/10.1037/h0074428
Witten, I. B., Steinberg, E. E., Lee, S. Y., Davidson, T. J., Zalocusky, K. A., Brodsky, M., Yizhar, O., Cho, S. L., Gong, S., Ramakrishnan, C., Stuber, G. D., Tye, K. M., Janak, P. H., & Deisseroth, K. (2011). Recombinase-driver rat lines: Tools, techniques, and optogenetic application to dopamine-mediated reinforcement. *Neuron, 72*, 721–733. https://doi.org/10.1016/j.neuron.2011.10.028
Yizhar, O., Fenno, L. E., Davidson, T. J., Mogri, M., & Deisseroth, K. (2011). Optogenetics in neural systems. *Neuron, 71*, 9–34. https://doi.org/10.1016/j.neuron.2011.06.004