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Problem-Solving, Bidirectional Naming, and the Development of Verbal Repertoires

Caio F. Miguel
California State University, Sacramento

We often solve problems by engaging in mediating strategies, such as talking to ourselves. In order to accurately use and respond to these strategies, we must "understand" or react appropriately to the products of our own verbal behavior. The term bidirectional naming has been used to describe the integration of both listener and speaker behaviors that leads to speaking with understanding. The current paper describes a series of studies that show that in the absence of either speaker or listener behaviors, participants often fail to solve problems in the form of matching-to-sample and categorization tasks. It is proposed that to solve these tasks participants must either react to their own speaker behavior or engage in covert imagining. It is hoped that the current paper stimulates research on the role of covert behavior in the development of problem solving skills.

Keywords: covert behavior, naming, private events, problem solving, verbal behavior

From a behavioral perspective, what is referred to as *cognitive processes* may be related to problem-solving (Skinner, 1974). Problems such as an algebraic equation, remembering what to buy at the store, or repairing a car, cannot be adequately analyzed by appealing solely to immediate observable stimuli and responses. Once a problem presents itself, a sequence of behaviors must occur before the solution is reached (Skinner, 1953, 1984). For instance, when thinking about what to buy at the grocery store, we may read items from a list or try to recite them as an attempt to produce discriminative stimuli for selecting what is needed. Skinner (1984) termed the responses that occur prior to reaching a solution as *precurrent*, which sometimes cannot be directly observed, as they happen at the covert level.

Although earlier versions of behaviorism (e.g., Hull, 1943; Tolman, 1948) proposed mediating (or organismic) variables (e.g., cognition, expectancies, habit, etc.) to explain why a stimulus did not evoke the expected response, or why a certain response would appear in the presence of several stimuli, these devices were theoretical constructs with assigned causal status independent from any functional relation with the environment (Moore, 2008). Skinner (1953, 1974) himself was quite critical of this practice. He referred to it as *mentalism*, since most of these hypothetical constructs were believed to occur at the *mental level*. Moreover, these constructs, which are used to explain behavior, are usually created after the behaviors that they are trying to explain have been observed. Take, for instance, the label "introvert," which may be used to explain why an individual does not talk much or socialize with others. This label cannot be used as an explanation given that it was derived from the set of behaviors it tries to explain. The same can be said of the common diagnosis of "autism." After seeing a child engage in repetitive behavior, one may be inclined to say that the behavior "is caused by autism." The problem, of course is that we know the child "has" (was diagnosed with) autism for, among other things, displaying repetitive behavior.[1] The main concern with these

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Correspondence concerning this article should be addressed to Caio F. Miguel, Department of Psychology, California State University, Sacramento, 6000 J. Street, Sacramento, CA 95819-6007. E-mail: miguelc@csus.edu

[1] This is likely a problem with all psychiatric diagnoses. They are labels derived from a set of behaviors and should never be used as explanations.

constructs is that they become the subject matter to be studied, rather than more obvious variables. Thus, instead of looking for variables that may have led to the development and maintenance of the behavior, the label is reified as a thing and endowed with causal status. According to Skinner (1974), this practice "has obscured the environmental antecedents which would have led to a much more effective analysis" (p. 165).

Even though some behaviorists may not be completely comfortable with studying variables that cannot be directly observed (e.g., Baum, 2011; Rachlin, 2017), Skinner was never concerned with the inaccessibility of mental events, but rather with their explanatory status; "the objection of the inner workings of the mind is not that they are not open to inspection but they have stood in the way of the inspection of more important things" (Skinner, 1974, p. 165). For Skinner, "the distinction between public and private is by no means the same as that between physical and mental." (Skinner, 1945, p. 285). Public and private events are both natural and affected by the same general laws of behavior. As a matter of fact, Skinner (1974) distanced himself from classical or methodological behaviorists, most of whom were only interested in studying observable events (Watson, 1913), by affirming that a science of behavior must provide "an alternative account of mental life" (p. 211). Hence, given that these private events are also part of the organism's environment, their role must be taken into account when we analyze behavior.

Problem-Solving

When solving problems, we take steps, or engage in a series of behaviors to reach a solution (Skinner, 1974, 1984). These behaviors can be anywhere in the overt-covert spectrum. Take for instance the simple math problem "298 × 12." To solve it, we would likely have to engage in a sequence of behaviors, some of which may be overt, such as writing the steps on a piece of paper, or covert, such as solving it "in our head" (Palmer, 1991). The common situation of trying to remember what to buy at a grocery store may involve some form of echoic rehearsal (Lowenkron, 1998). If asked to buy items such as wine, cheese, croissants, milk, and toilet paper, we commonly engage in some form of covert repetition (i.e., "wine, cheese, etc.") either on the way to, and/or when we arrive at the store, to produce discriminative stimuli that would evoke correct selection responses (Donahoe & Palmer, 2004).[2] Although it could be argued that the three-term contingency (i.e., the request, the selection of the products at the store, and some form of reinforcement) may account for this behavior, this analysis would not take precurrent responses into account. If there is a long delay between the request and the selection response, it is likely that the request evokes echoic behavior, which is preserved during the delay through self-echoic repetition. The product of this repetition generates stimuli that evoke the selection of the requested items. Often the echoic behavior and self-repetitions occur covertly. Precurrent behaviors may also occur if using a shopping list, which would serve as discriminative stimuli for (covert) textual behavior, whose product serves as discriminative stimuli to evoke the selection of the items (Keohane & Greer, 2005). The steps between the instruction and the selection are referred as *mediating behaviors* (e.g., Miguel, 2016; Osnes, Stokes, & Guevremont, 1988), where the sense of mediating here implies bridging a temporal gap by supplying additional discriminative stimulation, in this case verbal. Although some behavior analysts advise against taking verbal mediation into account (e.g., Rachlin, 2017), it would seem that each component in the task analysis of solving a problem is necessary when attempting to teach this skill to those who lack it.

Sautter, LeBlanc, Jay, Goldsmith, and Carr (2011) taught preschool children to utilize a problem-solving strategy to increase the number of answers to categorization questions ("tell me some animals/vehicles/kitchen items"). To answer these questions, the experimenters taught participants to engage in a series of self-prompts that included using group names (farm, zoo, and ocean animals) to produce previously trained intraverbals (e.g., Farm animals → sheep, horse, pig, cow). When asked the questions, children learned to generate discrimina-

[2] There may be other processes taking place when recalling a list of items at the grocery store. For instance, one item (e.g., wine) may serve as a discriminative stimulus for purchasing another (e.g., cheese) as they are usually purchased together.

tive stimuli to evoke intraverbal responses by stating the names of groups, selecting one group, followed by selecting a different group, and then saying the last group. When participants failed to provide complete answers, the experimenters prompted them to use these mediating responses (e.g., "use your rules"). The number of intraverbal responses increased for all children, who overtly self-prompted during initial test trials. Despite not engaging in audible self-prompts throughout, participants' correct responses remained high, and occurred in group clusters, suggesting that participants may have been self-prompting (verbal mediation) covertly. This study supports the literature suggesting that (covert) verbal behavior may serve to mediate complex performances (Miguel, 2016). As stated by Sautter et al. (2011), it is likely that "advanced speaker and listener repertoires are required for the intraverbal-based mediating response" (p. 243). Thus, it seems that participants' performances were dependent on a well-established *bidirectional naming* repertoire (Horne & Lowe, 1996; Miguel, 2016).

Bidirectional Naming

We may assume that to accurately use and respond to the mediating strategies described above, individuals must "understand" or react appropriately to the products of their own verbal behavior (Skinner, 1957). In the study by Sautter et al. (2011), for example, the vocalization *fish*, is classified as an intraverbal if it is under the control of verbal stimuli with no point-to-point correspondence with the response (e.g., the words *ocean* and *animal*) and is reinforced by a listener who "understands" the word *fish*. In other words, the word *fish* (auditory stimulus) must evoke, on the part of the listener, conventional behavior such as orienting toward a fish or perceptually "seeing," "smelling," or "tasting" it (as well as seeing or smelling other stimuli associated with fish, such as the ocean; Skinner, 1953). Speakers can also hear themselves say *fish* and react to their own vocalization. It has been argued that it is only when individuals can react as listeners to their behavior as speakers that they may be considered truly verbal (Carr & Miguel, 2013; Greer & Ross, 2008; Horne & Lowe, 1996; LaFrance & Miguel, 2014; Miguel, 2016). Additionally, verbal behavior is symbolic in nature, so when someone speaks, the words spoken (stimuli) are substitutable for their respective objects (Sidman, 1994).[3] In the study described above (Sautter et al., 2011), participants had to respond to their own verbal utterances by engaging in further speaker behavior (answering intraverbal questions), and likely (although not measured) reacting as listeners by orienting to any stimuli belonging to the same stimulus class as the word *fish*.

Miguel (2016) has used the term *bidirectional naming* (BiN) to describe the integration of both listener and speaker behaviors. We would say that someone "displays" a generalized BiN repertoire when the reinforcement of a listener relation is accompanied by the emergence of a speaker relation, without the need for training, or vice versa (Miguel & Petursdottir, 2009). The term was originally introduced by Horne and Lowe (1996), who described a developmental sequence by which children acquire the basic verbal relations (Skinner, 1957). Their verbal unit, originally termed *naming*, was presumed to play a crucial role in the development of meaning and symbolic behavior.[4]

The conditions necessary for the development of BiN are present during typical child-caregiver interactions. Initially, a child may be taught to orient to a particular object, for instance, a fish, in the presence of the caregivers' vocal (auditory) stimulus *fish*. The child may learn not only to orient to a particular fish, but also to everything else that has been called *fish* by her caregivers (e.g., picture, toy, etc.). Thus, the listener repertoire regarding the specific stimulus class is established. When the child starts to echo the vocal production of others, the caregiver may point to the fish in the fish bowl and ask the child to say *fish*. The echoic response *fish*, or any approximation, is either reinforced by the caregiver or automatically reinforced by the auditory product of the child's own vocal-verbal response (Longano & Greer, 2015; Vaughan & Michael, 1982). Because the child has already learned to orient toward the fish (behave as a listener) in response to

[3] Words are not perfect substitutes for objects. We may pet a dog but not the word *dog* (see Skinner, 1957, pp. 86–87).

[4] A symbol consists of an arbitrary stimulus (e.g., the printed word *fish*) that belongs to the same equivalence class as its respective object (an actual fish).

the auditory stimulus *fish* produced by others, hearing the same auditory stimulus, now as a product of her own echoic behavior may serve to occasion both listener and further speaker (echoic) behaviors. When the caregiver points to the fish and says, *fish*, the sight of a fish becomes a frequent antecedent for the echoic utterance *fish*. Consequently, the fish becomes a discriminative stimulus that evokes the verbal response *fish*, as a tact. Later, when the child is alone, the presence of a fish occasions the verbal response *fish* whose "auditory" product evokes the relevant listener behaviors of reorienting to the specific fish or any other fish with some physical resemblance. This bidirectional relation between listener and speaker repertoires is what comprises the object's name (see Greer & Longano, 2010; Horne & Lowe, 1996; and Miguel, 2016).

Although early bidirectional names may be established through this process, repeated exposure to echoic, listener, and tact relations across multiple objects, may lead to the establishment of a generalized BiN repertoire. Research has shown that a history of reinforcement of speaker and listener behavior with multiple exemplars leads to the establishment of BiN as a higher-order generalized operant in that after learning to tact a stimulus, an individual can respond to it as a listener or vice versa (e.g., Fiorile & Greer, 2007; Gilic & Greer, 2011; Greer, Stolfi, & Pistoljevic, 2007). More importantly, individuals may eventually learn to bidirectionally name objects solely by observing others tact them (Carnerero & Pérez-González, 2014, 2015; Pérez-González, Cereijo-Blanco, & Carnerero, 2014).

This generalized BiN repertoire may be one way in which arbitrary stimuli gain symbolic properties or topographically dissimilar stimuli come to acquire the same meaning. More specifically, common tacts and listener behaviors may establish stimuli as related or equivalent. For instance, when an individual can say *fish* in the presence of an actual fish and its printed representation (speaker behavior), and select or orient toward the fish and its printed representation (listener behavior), we could say that both stimuli occasion the same bidirectional name. If this were the case, the presence of one of them would evoke a (overt or covert) tact (saying *fish*), whose "auditory" product (the sound *fish*), would in turn evoke the listener behavior of reorienting toward, and selecting the member that is part of the same bidirectional name relation rendering them as equivalent. Thus, stimulus classes may be formed on the basis of common speaker and listener behaviors alone (Horne & Lowe, 1996).

The role of BiN in the formation of stimulus classes is usually investigated using categorization matching-to-sample (MTS) tasks, which can be conceptualized as a problem to be solved. In a typical MTS task, a sample stimulus is presented (e.g., the spoken word *fish*) followed by a series of (usually three) stimuli (e.g., the printed words, fish, shark, and dolphin), one of which serves as the positive comparison (e.g., the printed word fish). In some of the categorization tasks, more than one stimulus may be deemed correct (e.g., Lowe, Horne, Harris, & Randle, 2002). If both the sample and the comparisons occasion a common bidirectional name, the task (or problem) can be solved by engaging in mediating verbal behavior: tacting the sample, the product of which would evoke the selection of the correct comparison.

Common Bidirectional Naming

Several studies have shown that when children with and without disabilities learn to tact and engage in listener behavior, they can categorize pictures accurately (Lowe et al., 2002; Horne, Hughes, & Lowe, 2006; Horne, Lowe, & Randle, 2004; Kobari-Wright & Miguel, 2014; Lowe, Horne, & Hughes, 2005; Mahoney, Miguel, Ahearn, & Bell, 2011; Miguel & Kobari-Wright, 2013; Miguel, Petursdottir, Carr, & Michael, 2008; Ribeiro, Cavalcante, Bandeira, Sella, & Miguel, in press; Ribeiro, Miguel, & Goyos, 2015; Sprinkle & Miguel, 2012). In other words, when dissimilar stimuli occasion common speaker and listener behaviors, they become equivalent. This phenomenon has been termed common bidirectional naming (C-BiN; Horne & Lowe, 1996; Miguel, 2016). More importantly, when participants can tact but not engage in listener behavior, or when they can engage in listener behavior and not tact, they tend to fail novel categorization or matching tasks.

For example, Lee, Miguel, Darcey, and Jennings (2015) taught four children with autism (3- to 5-years-old) to select pictures of dogs in the presence of their dictated categories (i.e., toy dog, hound dog, work dog). After this training, the two participants with more advanced verbal skills correctly matched the pictures based on their categories, while the other two participants with more limited verbal skills did not. The participants who matched correctly were the ones who accurately tacted these categories. In other words, after listener training, these participants tacted the pictures by category with no direct training. On the other hand, the two participants who failed to match did not accurately tact the pictures. These results add support to the notion that the bidirectional relation between speaker and listener behaviors played a role in the emergence of categorization, in that participants had to tact the sample (e.g., say "hound dog"), the product of which evoked the listener response of selecting the correct comparison (e.g., the picture of the other hound dog).

In a series of experiments by Miguel et al. (2015), college students learned to tact two arbitrary pictures next to each other (compound stimulus) as either "same" or "different" based on their experimentally defined class membership (A1B1C1 and A2B2C2).[5] In other words, if the two stimuli belonged to the same class (e.g., A1B1), participants learned the relational tact, "same," and if the two stimuli belonged to two different classes (e.g., A1B2), participants learned the relational tact, "different." After this training, experimenters tested to see if participants would tact novel pairs of trained stimuli as either "same" (e.g., B1A1) or "different" (e.g., A1C2), as well as match compounds in an analogy MTS test. During the analogy test, a compound sample was presented followed by two compound comparisons. For example, in the presence of a sample comprised of two stimuli belonging to class 1 (e.g., B1A1), participants were supposed to select the (analogous) comparison that contained two stimuli belonging to class 2 (e.g., B2A2), rather than the comparison with stimuli belonging to different classes (e.g., B2A1). When presented with a sample comprised of two stimuli belonging to different classes (e.g., C1B2), participants were supposed to select the (analogous) comparison that contained stimuli belonging to different classes (e.g., C2B1), rather than the comparison with stimuli belonging to the same class (e.g., C2B2). Many of participants who underwent this training (Experiments 1–3), passed the analogy tests without the need for remediation.

In the final experiment, Miguel et al. (2015) trained six participants to tact individual stimuli belonging to class 1 as "vek," and to class 2 as "zog" prior to being exposed to relational tact and analogy tests as described above. Four of six participants passed all tests, while two participants failed the analogy matching tests. Interestingly, even though the participants who failed analogy tests accurately tacted individual stimuli as "vek" or "zog," when presented with stimulus compounds, they did not tact their relationships as "same" or "different." In other words, participants matched compounds based on their common relational tact. Compounds tacted as "same" were treated as analogous, while compounds tacted as "different" were also treated as analogous. Thus, when solving the analogy task, participants must have tacted the sample as either "same" or "different" (speaker behavior), the product of which served as a discriminative stimulus that occasioned the selection of the correct "same" or "different" comparison (listener behavior). This interpretation has been corroborated by the results of a recent unpublished replication (Meyer, Cordeiro, & Miguel, 2017), in which college students were required to vocalize during analogy tests. Participants who passed the analogy tests were the ones who engaged in both relational tacts (e.g., saying "same"), as well as in relational listener behavior (e.g., selecting the correct compound when hearing "same").

The research on C-BiN is not without its limitations, as the evidence for the interdependence between listener and speaker behaviors on arbitrary matching is correlational in nature. For instance, when training the listener component alone produces accurate matching and speaker behavior, we cannot safely argue that both listener and speaker (i.e., BiN) were necessary, since the emergence of the untrained component could be a mere correlate of the training procedure, playing no causal role in the observed performance. When the listener component does not produce the matching performance and also does not produce speaker behavior, a functional relation between BiN and

[5] Letters refer to stimulus exemplars and numbers to class membership. Class 1 was named "vek" and class 2, "zog."

categorization cannot be established either. It is only when a failure to perform during MTS tests is remedied by teaching the missing component of BiN that one can argue that both listener and speaker behaviors were (in this case) necessary. Although only a few participants have failed to categorize after training, the absence of one of the components of BiN is often correlated with failures in MTS tests. However, a trial-by-trial analysis in some of these studies (e.g., Miguel et al., 2008) shows instances in which participants performed incorrectly on a specific category-sort trial despite the fact that they had been seen to correctly tact the sample, and select the pictures given their names. This performance is consistent with Lowenkron's (1998) *joint control* analysis.

Joint control is defined as

> a discrete event, a change in stimulus control that occurs when a response topography, evoked by one stimulus (e.g., the sample) and preserved by rehearsal, is emitted under the additional (and thus joint) control of a second stimulus, (e.g., the comparison). (p. 332)

Based on this analysis, when participants failed to tact the comparisons, they would have not categorized correctly. A failure to tact the comparisons would prevent an additional stimulus (the auditory stimulus produced by tacting the comparison) from jointly controlling the specific topography, which would serve to evoke the categorization response. On the other hand, participants who categorized despite their lack of accurate listener behavior could have done so by tacting the sample, covertly rehearsing this topography, and tacting each of the comparisons, as required to produce joint control.

Miguel (2016) argued that joint control is a form of BiN as it seems to be a product of the same caregiver-child interactions described by Horne and Lowe (1996).[6] Once tacts and listener responses have been established, the sight of a stimulus, a goldfish for instance, may evoke speaker (saying *fish*) and listener responses (orienting to, selecting) toward same (the actual fish) and similarly named objects (the picture of a fish). Orienting toward the picture would yield contact with a visual stimulus (the picture), which may serve to evoke a previously acquired tact (saying *fish*). Thus, it is possible that subsequent listener responses may be controlled by not only the auditory stimuli (e.g., the dictated word *fish*), but the additional (joint) control of the auditory product of the tact. If this were the case, during the grocery shopping example above, when an item on the shelf (bottle of wine) evokes the same verbal response (saying "wine") being self-rehearsed ("wine"), the item is "found," and subsequently selected (Lowenkron, 1998).

C-BiN and joint control may serve as models to understand the underlying mechanisms responsible for some of the (cognitive) processes necessary for problem solving. However, there are several occasions in which the type of verbal mediation necessary to complete a task includes chains of intraverbal responses, as described in Sautter et al. (2011).

Intraverbal Bidirectional Naming

Stimuli may become related or equivalent due to common speaker and listener behaviors as described above, as well as through intraverbal relations that may be established among stimulus names. For example, learning to say "milk comes from the cow" establishes the stimuli *milk* and *cow* as intraverbally related. In other words, they would exert control over the emission of each other. Additionally, stimuli belonging to the same class as the word *cow*, (e.g., the picture of a cow), would become related with stimuli belonging to the same class as the word, *milk* (e.g., the picture of a milk carton). Hence, seeing any stimuli belonging to the class *cow* would evoke the tact of saying *cow*, the product of which would evoke the intraverbal *milk*, whose product would serve as a discriminative stimulus for listener responses toward any stimuli belonging to the class *milk* (i.e., looking or orienting to the milk carton, conditionally seeing or tasting milk). This has been termed *intraverbal bidirectional naming* (I-BiN; Horne & Lowe, 1996; Miguel, 2016).

I-BiN may serve to describe a behavioral process by which participants may solve visual-visual arbitrary MTS tasks after learning to intraverbally relate stimulus names (Jennings & Miguel, 2017; Ma, Miguel, & Jennings, 2016; Petursdottir, Carp, Peterson, & Lepper, 2015; Santos, Ma, & Miguel, 2015). Petursdottir et al. (2015), for instance, taught 10 preschool children to tact arbitrary pictures with individual

[6] For an alternative interpretation see Lowenkron (1996, 1997).

names (e.g., "Psi" and "Kibi"), and to relate these names intraverbally (e.g., "Psi goes with Kibi") in the absence of their visual counterparts. The authors tested to see whether visual stimuli became related by exposing participants to a matching task consistent with symmetry (BA),[7] and whether this performance was dependent on the emission of intraverbals ("Kibi goes with Psi") also consistent with symmetry (B'A'). The assumption was that to solve this task, participants would have to tact the sample visual stimulus (e.g., "Kibi"), the product of which would evoke the intraverbal, "Kibi goes with Psi," leading to the correct selection. Ten children were exposed to tact training, then A'B' intraverbal training, and subsequently tested on AB and BA emergent relations, as well as the B'A' intraverbal. Out of five participants who passed the matching-to-sample tests, only one passed the symmetrical intraverbal test, challenging the bidirectional naming explanation. In other words, these participants were most likely not engaging in intraverbal behavior while solving the MTS task. However, the population under investigation may not have been ideal for the study of I-BiN. Baseline tact and, most importantly, intraverbal relations were slowly acquired and maintained. Additionally, young participants may not have had sufficient language skills to "derive" symmetrical intraverbals—a skill shown to be brought about after a history of multiple-exemplar training (Pérez-González, García-Asenjo, Williams, & Carnerero, 2007). Thus, it is possible to assume that these participants did not have the prerequisite skills to form arbitrary visual classes via I-BiN.

In a follow-up study with six college students (Santos et al., 2015), tact and intraverbal training (A'B') was sufficient to establish visual stimulus relations consistent with baseline (AB). In a second experiment, the same tact and intraverbal training produced MTS and intraverbal relations consistent with baseline and symmetry (BA, and B'A,' respectively) with additional four college students. Moreover, intraverbal vocalizations emitted during posttests supported the notion that verbal behavior may have mediated participants' matching performances. When asked to vocalize during MTS tests, participants tacted samples and comparisons, as well as engaged in trained and self-generated intraverbals. The fact that they performed similarly in the MTS tasks in the presence and absence of instructions to talk aloud suggests that overt vocalizations may have corresponded to covert ones. It is possible that when first presented with the MTS tasks, participants matched the pictures based on learned intraverbal relations. However, as samples and comparisons kept appearing together during subsequent trials, samples may have acquired conditional control over positive comparisons, making verbal mediation no longer necessary (e.g., Oliveira-Castro, Coelho, & Oliveira-Castro, 1999).

Additional evidence for I-BiN comes from a series of experiments (Jennings & Miguel, 2017; Ma et al., 2016) in which college students demonstrated MTS performances consistent with symmetry and equivalence (i.e., BA/CB and AC/CA) following tact training, listener testing, and baseline (A'B' and B'C') intraverbal training. All of the participants emitted experimentally defined, self-generated tacts, or intraverbally named the correct sample-comparison pairs at some point during MTS posttests. Because experimental stimuli shared no physical similarities (e.g., shape, size, and color) and had very different names (e.g., "cardinal" and "dogwood"), participants could have only correctly matched stimuli based on the intraverbal relations learned during training. Therefore, when presented with the sample (e.g., the picture of dogwood), participants tacted it, the product of which evoked the intraverbal relation (e.g., "the bird for dogwood is cardinal"), whose product evoked the selection of the correct comparison (e.g., the picture of cardinal). With only one exception, the participants who failed intraverbal relations tests also failed to match stimuli (Jennings & Miguel, 2017), suggesting that their MTS performance depended on verbal behavior.

Although the aforementioned experiments led to the interpretation that I-BiN facilitated novel MTS performance, the time it took for

[7] Symmetry and transitivity tests are used to verify that stimuli belong to the same class or are equivalent. These tests are conducted in matching-to-sample format. After learning to select B in the presence of A (AB), and C in the presence of B (BC), symmetry would consist of selecting A in the presence of B (BA), and B in the presence of C (CB). Transitivity would consist of selecting C in the presence of A (AC) and A in the presence of C (CA, usually referred to combined symmetry and transitivity, or equivalence test).

participants to respond on these tasks (latency) diminished throughout task exposure (Jennings & Miguel, 2017; Ma et al., 2016). This result led authors to conclude that verbal behavior may have only been necessary (or used) during the establishment of baseline intraverbal relations and initial MTS trials.

Visual Bidirectional Naming

As previously discussed, to assess the role of verbal mediation as a problem-solving strategy, previous studies have correlated intraverbal behavior and MTS performances, measured response latency and unprompted vocalizations during MTS tasks, and conducted both protocol analyses (talk aloud procedures), as well as postexperimental interviews. During MTS posttests, most participants vocalized experimentally defined tacts and intraverbals, and they also generated their own verbalizations. These responses were often evoked by specific physical features of stimuli. Some participants from Ma et al. (2016) stated: "This big fat flower belongs with that little thing, yellow hammer, and they are both from Alabama," and "This little flower goes with the big bird that's red." (p. 417–418). These examples suggest that participants may have been attending to (and their behavior was under control of) the visual characteristics of stimuli.

Jennings and Miguel (2017) noted that because their participants were first exposed to tact training, it is possible that during subsequent baseline intraverbal training (A'B'; B'C') they were visualizing or imagining visual stimuli whose names were being rehearsed intraverbally. This form of conditioned seeing would be analogous to a visual-visual baseline training task in which AB and BC stimuli are paired together (Layng & Chase, 2001). Interestingly, Jennings and Miguel reported that some participants stated they had "associated words with pictures, thinking of the pictures while going through the statements" or "visualizing the pictures while learning the statements." Given that pictures and their names were members of the same class, when names were related intraverbally, it is not surprising that their respective visual counterparts would also become related. Moreover, when learning to intraverbally relate stimulus names, participants could likely (covertly) "see" these stimuli. Whether this type of covert visualization occurred and aided training and testing performance remains unclear. Future investigations should manipulate the order or tact and intraverbal training, as well as measure (albeit indirectly) visual imagining during both training and testing.

Horne and Lowe (1996) argued that during the acquisition of the (bidirectional) naming repertoire, the caregiver's vocalization during listener training may come to elicit conditioned responses such as (covertly) seeing the object being spoken about. During this training, the caregiver may request an object (e.g., "go get the doll") that the child has already learned to engage with (e.g., point to, orient toward, or play with a doll), and model the appropriate listener response of retrieving it. Given that the caregiver's vocalization precedes the sight of the object, the vocalization itself may elicit conditioned seeing (i.e., imagining) the object prior to encountering it. The caregiver acknowledgment of correct listener responses (retrieving the object) would also follow the child's behavior of imagining the object, establishing it (the child's behavior) as an operant response under control of the object's name spoken by the caregiver (auditory stimulus). Additional evidence that this form of imagining is an operant would come from its functional relation with, for example, specific motivating operations, such as when a child is more likely to imagine or think about the doll after not having played with it for a while (Skinner, 1953).

Based on the aforementioned analysis, an individual who displays a generalized BiN repertoire in which the teaching of either speaker or listener behavior would suffice to establish both, would also learn to imagine the object after learning to tact it or react to it as a listener. During tact training, the presence of the object would evoke seeing it as an unconditioned response, while during listener training, the name of the object (auditory stimulus) would also evoke seeing it, as a conditioned response (i.e., covertly), even prior to encountering it which could be better described as imagining.

During C-BiN categorization experiments (e.g., Kobari-Wright & Miguel, 2014; Miguel & Kobari-Wright, 2013), in which participants learned to either tact or select stimuli with a common name (e.g., "hound dog"), it is possible that when attempting to solve visual-visual MTS tasks, participants not only tacted the sample by saying "hound dog," but also saw (or imagined) other stimuli named "hound dog." Thus, seeing the sample could have led to imagining other stimuli, the product of which evoked the selection of the correct comparison. During I-BiN experiments, in which participants learned to tact stimuli with individual names, and then relate those names intraverbally, it is possible that during MTS tasks, the presence of a sample (e.g., picture of a horned lizard) evoked (a) a tact (e.g., "horned lizard") whose product could have evoked intraverbal responses (e.g., "pecan" and "mockingbird"), which in turn generated discriminative stimuli for the correct selection; and (b) a conditioned response of seeing (imagining) other objects whose names have been related intraverbally (pictures of pine and yellowhammer), which served as discriminative stimuli for selecting the correct comparison. If the correct comparison is selected because it matches the product of the conditioned seeing response (covert visual stimulus), then the task would be akin to identity matching.

The relation between imagining and reacting to covert visual stimuli can be considered analogous to the relation between speaker and listener responses, respectively. Seeing objects in either their presence or absence (i.e., imagining) may be analogous to speaking (overtly or covertly), while reacting to visual stimuli may be analogous to listening. Skinner (1953) made a similar distinction in that seeing, or engaging in covert problem-solving, can be compared with manipulative responses, whose results may produce discriminative stimuli for the overt "solution."

Visual imagining as a problem-solving strategy must also involve a bidirectional relation between imagining and reacting to its sensory products. The presence of a public visual stimulus, for instance, would evoke seeing it, imagining other stimuli related to it, and so forth, the products[8] of which would evoke further responses that would include reorienting toward the public visual or other stimuli that are physically similar or that evoke the same image.[9] Although further refinements are necessary, for now we may refer to this process as *visual bidirectional naming* (V-BiN), with the important caveat that this may not be a verbal relation.[10]

Kisamore, Carr, and LeBlanc (2011) designed an experiment to directly assess the role of visual imagining in problem-solving. Similar to Sautter et al. (2011), four typically developing children were asked to answer categorization questions ("What are some animals/furniture/kitchen items/vehicles?"). Before visual imagining training, each participant learned to tact individual pictures (e.g., shark) and their categories (e.g., animal), place the pictures on a background scene, and state the names of specific subcategories (e.g., ocean). During visual imagining training, the experimenter presented a visual example of a scene that could be imagined when thinking of a particular subcategory, and asked participants to look at the scene for 10 s. Subsequently, the experimenter told participants that she was going to close her eyes, closed her eyes, presented a gray screen, and told participants that this is what it looks like when she closes her eyes (referring to the gray screen). The experimenter told the participants that she had seen an item, as the item was appearing on the screen (e.g., a shark). The experimenter remained with her eyes closed until all items were presented (every 5 s). Next, the experimenter taught participants to look at the scene, close their eyes, imagine it, and tell what they saw. The scenes were faded until participants correctly responded in their absence, with their eyes closed. After learning how to imagine each scene and specific items that belonged to them, participants were taught to respond to categorization questions by being told, for example, to imagine all places that animals go and tell what they see. Results showed that participants' correct responses to categorization questions did not increase until participants learned the visual

[8] Kisamore, Carr, and LeBlanc (2011) suggested that to be conceptually systematic with behavior analysis, visual imagining should be interpreted as behavior that is not separate from the object that evoked it. However, imagining (as any other behavior) may result in response products which are themselves stimuli that may acquire control over other behaviors. Although unobservable (private), these stimuli never occur in isolation, but always as products of (overt or covert) behaviors. Thus, private visual stimuli are not equivalent to stored mental images.

[9] Objects that evoke the same covert seeing behaviors may become members of the same class in a process analogous to common bidirectional naming.

[10] However, V-BiN seems to derived from the same contingencies that lead to the development of verbal behavior.

imagining strategy and were prompted to use it. Moreover, participants' responses were grouped by subcategory (farm, ocean, zoo), suggesting that their responses were under control of the specific scenes being imagined. These results show that overt behavior can be under control of private visual stimuli arising from operant seeing, which adds support to the premise that visual imagining may be used as a problem-solving strategy. It can be argued that to solve this task, the experimenter's question had to evoke operant seeing (i.e., imagining an ocean with a dolphin, a fish, a lobster, and a shark), the product of which served as a discriminative stimulus for naming these items. Although not measured, visual imagining may have also led to "listener" responses, such as selecting pictures of the named items.

Interestingly, Mellor, Barnes, and Rehfeldt (2015) extended these results by teaching preschool children to solve similar tasks (e.g., "What is an eagle sound?") through auditory imagining. Their results suggest that mediation may occur not only via covert verbal behavior and imagining, but also though covert hearing. As Skinner (1953) suggested, "Even when covert behavior is mainly verbal, other types of private responding frequently occur" (p. 274). Hence, the analysis above (i.e., V-BiN) could be extended to other possible forms of mediation such as covert hearing or "auditory imagining" (Mellor et al., 2015).

These processes are behavioral in nature, as they had to be acquired overtly prior to receding to the covert level (Skinner, 1945, 1953, 1957). Thus, with the exception of being unobservable, these private events (i.e., covert behaviors and private stimuli) do not differ from their public equivalents. As stated by Skinner (1953),

> In mental arithmetic one multiplies, divides, transposes, and so on seeing the result in each case, until a solution is reached. Presumably much of this covert behavior is similar in form to the overt manipulation of pencil and paper; the rest is discriminative behavior in the form of seeing numbers, letters, signs, and so on, which is similar to the behavior which would result from overt manipulation. (p. 273)

Conclusion

Solving a problem may involve a series of responses that when emitted increase the probability of reaching a solution (Skinner, 1953). These responses, termed precurrent, lie anywhere on the overt-covert spectrum. Hence, it is possible to conceptualize problem-solving as a chain or series of behaviors (overt or covert), each producing a discriminative stimulus (public or private) that would evoke the subsequent response, until the last response is emitted. The response that contacts reinforcement is called the solution.[11] A stalled car, for example, could evoke a multitude of behaviors such as looking for a jumper cable, asking someone to help jumpstart the car, and so on.[12] Although all of these behaviors are public, one may think what to do prior to, or while jumpstarting the car (e.g., shut off the ignition in both cars, engage parking brakes, attach one of the red clips to the positive terminal of the dead battery, attach the other clip to the positive terminal of the other car, and so on). Thinking about each of these steps before performing them may be a way to construct useful discriminative stimuli to reach the solution. "What a chess player has in mind may be other moves he has made as he has played the game covertly to test the consequences" (Skinner, 1974, p. 106). Although it may be easier to construct discriminative stimuli in verbal form, as they can be easily communicated to others and do not require any environmental support, one can also imagine these steps (Skinner, 1953, 1974).

It has been argued that to think verbally, one must react as a listener to his or her own verbal behavior (Horne & Lowe, 1996). Thus, effective problem-solving that involves sequences of verbal responses, as necessary in some of the categorization MTS tasks described above, may depend upon being a speaker-as-one's-own-listener (Greer & Speckman, 2009) or the generalized BiN repertoire (Miguel, 2016). Research on BiN usually involves teaching participants speaker (tacts and intraverbals) and listener responses, so they can generate their own verbal stimuli that would serve to evoke correct responses (solution) during MTS or categorization tasks (e.g., Jennings & Miguel,

[11] Palmer (1991) proposed that to solve a problem, we not only generate stimuli to control precurrent responses, but we must also "recognize" the solution.

[12] Not all problem-solving involves chains of behaviors. One may engage in several different precurrent responses that are not sequenced until the solution is "recognized." An example would be trying to remember what you were wearing last Monday.

2017). The general finding is that a solution cannot be reached if either speaker or listener behaviors are missing (Miguel, 2016), or cannot be emitted (e.g., Clough, Meyer, & Miguel, 2016). However, future research should focus on further assessing the relationship between verbal problem-solving, thinking, and BiN. It is also possible that BiN plays an important role in the development of complex relations such as comparing stimuli by size, quantity, and so forth (e.g., Whelan, Barnes-Holmes, & Dymond, 2006).

Covert seeing (or visual imagining), and covert hearing (or auditory imagining) may also be involved in the sequence of behaviors necessary for reaching a solution, as shown by Kisamore et al. (2011) and Mellor et al. (2015), and as evidenced by participants' reports in some I-BiN studies (e.g., Jennings & Miguel, 2017). Even though it has been argued that these covert behaviors (visual imagining, more specifically) are established during the same child-caregiver interactions responsible for the development of BiN (Horne & Lowe, 1996), the relationship between BiN and conditioned seeing and hearing must be further clarified.[13]

BiN has been shown to play an important role in the establishment of many complex skills, such as reading, writing, and spelling (e.g., Eby, Greer, Tullo, Baker, & Pauly, 2010; Greer, Yaun, & Gautreaux, 2005). For this reason, it has been considered a cusp skill (Greer & Ross, 2008; Hixson, 2004; Rosales-Ruiz & Baer, 1997) that should be taught to those who do not readily show it, including children with developmental disabilities (Fiorile & Greer, 2007; Greer et al., 2007). If it is only when children acquire BiN that they can effectively react to their own verbal behavior (and likely to the products of their own conditioned seeing), then it must play a crucial role in the development of thinking (Horne & Lowe, 1996). If this is the case, then BiN should be considered the most important skill to be established during the course of language development.

It is important to note that BiN is not being used as an explanation, but as a description of how individuals learn to respond as both speakers and listeners, and how these behaviors may be emitted in the process of solving a complex task. Thus, an individual does not respond correctly to an arbitrary MTS task because he or she "has" BiN. Rather his or her correct responses to the task may involve the emission of the behaviors that are subsumed under the BiN relation. These behaviors must themselves be explained via a careful analysis of reinforcement histories and contingencies, often involving multiple exemplar instruction. Horne and Lowe (1996) described a detailed history by which individuals learn to react as listeners to their own speaker behavior, and how this may lead to a generalized repertoire, so the establishment of either relation may lead to the emergence of its counterpart. As we learn about the importance of the effects of BiN on the acquisition of other more complex behaviors, it becomes imperative that we also learn effective ways to teach it (Greer & Ross, 2008).

Unfortunately, some aspects of the behavioral processes described above are not directly observable, but inferred from what is currently known about behavior-environment relations. The difficulty in isolating these (covert) variables leads researchers to resort to this sort of correlational methodology, and make interpretations about unobserved processes. However, "in any science, interpretations not only resolve mysteries; they can guide research. Thus inferences about private events play an important role in behavior analysis, just as analogous inferences play a role in other sciences" (Palmer, 2011, p. 203). So the question is not whether to study BiN or private events, but how to do so in a way that is conceptually systematic with behavior analysis. Even though the analysis above relies on unobservable stimuli-response relations, the speakers' responses were acquired publicly, and later receded to the covert level (Skinner, 1945). The functional control of private stimuli upon behavior depends on their correlation with public stimuli. Thus, private events do not serve as the ultimate explanation for behavior, as their function must be explained via the histories of reinforcement responsible for the establishment of their public correlates (Tourinho, 2006).

In conclusion, the study of covert behavior and private stimulation as "physical things" seems important as it may provide a monistic alternative to these so called "mental events"

[13] For recent attempts to assess the relationship between BiN and conditioned seeing, see Mercorella (2017) and Shanman (2013).

(Skinner, 1974). It may help us understand, behaviorally, how we think and solve problems. Moreover, those attempting to teach complex skills such as thinking, recalling, and problem-solving to children with disabilities, would likely appreciate a careful task analysis of the specific behaviors involved.

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