Using Operant Techniques With Humans Infants

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The purpose of the current article is to highlight the importance of operant techniques in developmental research. Although many researchers employ operant techniques within their individual fields of study, the pervasive nature of these techniques is not often acknowledged in the general literature. The present article describes the history of the use of operant techniques in developmental contexts and summarizes current basic research using this approach across a variety of disciplines. In addition, the recent use of operant techniques to explore cognitive development and the unique advantages it brings to this field over more traditional approaches are highlighted. Finally, the application of these techniques to clinical contexts is presented to demonstrate the usefulness of operant procedures with clinical populations.
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Operant learning has long been used as a tool for investigation of a wide range of issues. A substantial portion of current learning theory, as well as clinical and basic research applications, draws from this body of work. The use of operant techniques in developmental investigations, while substantial, is not often discussed or acknowledged in the general literature, and awareness of the application of these techniques to clinical situations is also sometimes seen as inadequate. In addition, the use of operant techniques to explore the development of cognitive concepts has been gaining momentum and may help address some of the interpretative problems that arise from using other measures, such as habituation of an orienting response. The goal of the present article is to describe the history of the use of operant techniques in developmental contexts, summarize current basic research using this approach, address the issue of using operant procedures in the evaluation of cognitive concepts, and then present briefly a set of clinical investigations that have used these techniques in examining issues of interest to the developmental research community.

An Abbreviated History of Operant Learning in Infants

The first attempts to demonstrate the basic principles of operant learning in human infants were published primarily during the 1950's and 1960's. Prior to this time, many developmental psychologists believed than an infant's brain lacked the developmental maturity needed to acquire traditional operant learning and classical conditioning. As technology became more sophisticated and researchers became more astute in choosing behaviors that were appropriate for an infant's unique behavioral milieu, researchers began to demonstrate that infants could display the basic principles of operant learning. For example, Lipsitt and colleagues studied multiple aspects of infant sucking behaviors using operant conditioning (Clifton, Siqueland, & Lipsitt, 1972; for review see Lipsitt, Crook, & Booth, 1985; Lipsitt & Kaye, 1964; Lipsitt, Kaye, & Bosack, 1966; Siqueland & Lipsitt, 1966), as well as other aspects of operant conditioning, relating sucking and heartbeat (e.g., Lipsitt, Reilly, Butcher, & Greenwood, 1976). (See also Weisberg & Rovee-Collier, 1998, pp. 325-333, for a review of the early history of operant learning in human infants).

A review of the literature following those seminal studies reveals a wide variety of flexible operant learning tools for use with infants, in terms of both the operant response and the type of reinforcement used. For example, infants will display operant head-turning to suck on a nonnutritive nipple (Siqueland, 1968), for auditory-visual reinforcement (Berg & Boswell, 1998; Goodsitt, Morgan, & Kuhl, 1993; Montgomery & Clarkson, 1997) and for social interaction (Tyler & McKenzie, 1990). Infants will show operant sucking for the sound of a heart beat (DeCasper & Sigafoos, 1983) or for the sound of singing (DeCasper & Carstens, 1981). Infants have been trained to use their hands to operate various manipulanda, including a sphere-shaped switch, touch-sensitive panels and touch-sensitive computer monitors (Bailey, Deni, & Finn-O'Connor, 1988; Darcheville, Riviére, & Wearden, 1993; Gerhardstein, Kraebel, Gillis, & Lassiter, 2002; Rheingold, Stanley, & Cooley, 1962; Simmons & Lipsitt, 1961) as well as engage in arm pulls for auditory-visual reinforcement (Alessandri, Sullivan, Imaizumi, & Lewis, 1993; Timmons, 1994). Infants can show operant kicking for only visual reinforcement, only auditory reinforcement, or for both (Kraebel, Fable, & Gerhardstein, 2004; McKirdy & Rovee, 1978; Rovee & Rovee, 1969). Neonates will show operant directional motility for tactile and kinestethic reinforcement from a stuffed toy that simulates a rhythmic breathing pattern (Thoman & Ingersoll, 1993). Infants have also shown operant vocalization for both social reinforcement (Ramey & Ourth, 1971; Todd & Palmer, 1968) and nonsocial reinforcement (Tomlinson-Keasey, 1972), although it should be noted that there is a debate as to whether vocalizations for social reinforcement follow principles of operant learning; see Poulson and Nunes (1988) and Bloom (1979) for critiques of this literature.

Use of Operant Techniques in Basic Developmental Research

The demonstration that infants display the basic principles of operant learning across a variety of tasks has allowed researchers to use operant procedures as a tool to explore various aspects of human infant development. Operant learning procedures have been used to examine emotional/social development, perceptual development, and learning and memory processes. For example, in the area of emotional/social development, Gerwitz (1972) presented a theory of infant human attachment based on principles of operant conditioning, and several researchers have examined correlations between different aspects of temperament and infants' performance in operant tasks (Dunst & Lingerfelt, 1985; Fagen, Ohr, Singer, & Fleckenstein, 1987).

In the realm of perceptual development, operant training has been used to examine infants' auditory thresholds for pure tones and noise bursts (Berg, 1991; Berg & Boswell, 1995), as well as their ability to discriminate harmonic tonal complexes (Montgomery & Clarkson, 1997). de Schonen (1990) demonstrated that operant procedures could be used to assess discrimination of faces, and Dunst (1984) used operant procedures to examine visual attention. Aspects of feature detection and visual search (Treisman, 1988, 1991; Treisman & Gelade, 1980) have also been examined using operant procedures (Bhatt & Rovee-Collier, 1997; Bhatt, Rovee-Collier, & Weiner, 1994; Gerhardstein, Liu, & Rovee-Collier, 1998; Gerhardstein, Renner, & Rovee-Collier, 1999; Rovee-Collier, Hankins, & Bhatt, 1992). For example, Adler, Inslight, Rovee-Collier, and Gerhardstein (1998) trained 3-month-old infants to kick to move a mobile displaying either 'R' or 'P' characters. The important difference, from the perspective of Treisman's account of visual search, is that the R is a P with an extra feature (and conversely, the P is an R with one feature removed). Thus, Treisman's theory predicts (and Triesman and Gelade have shown) that an R will "pop-out" from a background of P-distractors, but that the reverse arrangement will not elicit a pop-out effect, resulting in what Triesman termed a "search asymmetry". Adler et al. (1998) found that 3-month-olds show the same asymmetry in search for these features: Following training with a mobile displaying all 'R' characters, the infants gave a recognition response to a mobile displaying one familiar 'R' and 6 novel 'P' characters, but the reverse situation did not elicit a recognition response. Other investigations using the mobile method have investigated various aspects of visual search in infants (Bhatt et al., 1994; Gerhardstein et al., 1998; Rovee-Collier, Bhatt, & Chazin, 1996), and using a touch screen operant method in children (Gerhardstein et al., 2002; Gerhardstein & Rovee-Collier, 2002). These investigations have firmly established that infant visual perception includes an active, although not mature (Bhatt & Rovee-Collier, 1994; Gerhardstein et al., 2002; Gerhardstein & Rovee-Collier, 2002) system for rapid detection of perceptually important visual features.

The use of operant procedures to understand human infant development has had its largest impact in the area of learning and memory. For example, DeCasper and Carstens (1981) and Floccia, Christophe and Bertoncini (1997) examined the influence of different learning contingencies using nonnutritive sucking in infants less than 3 days old. Hildreth and Hill (2003) examined the role of retrieval processes in infants' retention of newly acquired and reactivated memories. The most prolific contributor, however, to understanding learning and memory processes in human infants using an operant procedure is Carolyn Rovee-Collier (Rovee & Fagen, 1976; Rovee-Collier & Capatides, 1979; Rovee-Collier, Hayne, & Colombo, 2001; Rovee-Collier & Sullivan, 1980; Rovee-Collier, Sullivan, Enright, Lucas, & Fagen, 1980). Rovee-Collier has focused on issues related to infant memory for much of her career, and the interested reader should refer to Rovee-Collier et al. (2001) for a lengthy presentation of investigations of the development of memory using operant conditioning. Rovee-Collier and her colleagues have studied the influence of retention intervals (Sullivan, Rovee-Collier, & Tynes, 1979) as well as massed and distributed practice (Enright, Rovee-Collier, Fagen, & Caniglia, 1983; Vander Linde, Morrongiello, & Rovee-Collier, 1985) on learning and memory processes. They have explored the role of reactivation treatments/reminder cues in memory processes (e.g. Boller, Rovee-Collier, Borovsky, O'Connor, & Shyi, 1990; Fagen, Yengo, Rovee-Collier, & Enright, 1981; Hill, Borovsky, & Rovee-Collier, 1988; Rovee-Collier & Sullivan, 1980; Rovee-Collier et al., 1980), and they have examined the role of contextual influences on learning and memory (Rovee-Collier, Griesler, & Earley, 1985). Finally, the work of Rovee-Collier and her colleagues has been pivotal in addressing theories of multiple memory systems (Gerhardstein, Adler, & Rovee-Collier, 2000; Rovee-Collier et al., 2001).

Use of Operant Techniques to Examine Cognitive Processes

The use of operant procedures to examine infant development has recently expanded into realm of cognitive development. Below, we review a list of these procedures, with the tacit understanding that this is not an exhaustive list, and that the work of a number of the researchers listed above would also occur as part of such a list.

Categorization

The development of categorization has been investigated using multiple techniques (see Wasserman & Rovee-Collier, 2001 for review). Bomba and Siqueland (1983) published one of the first such investigations, examining infants' use of prototypes in a shape category test. Greco, Hayne, and Rovee-Collier (1990) used the mobile conjugate reinforcement procedure to investigate 3-month-olds' capacity for categorization. Greco et al. trained infants to kick to move an overhead crib mobile using a 4-day procedure. The infants saw three mobiles during each of three daily sessions (in a different order each day). The mobiles all displayed a set of toy blocks with a large numeral "2", but differed in terms of the color of the blocks (red, blue, or green). Infants were then tested on the 4th day (24-hour delay) with the same "2" blocks, but in a novel color (e.g., yellow). Pilot testing had established that infants were capable of discriminating between all of the colors used, but the infants in the test following multiple color exposure showed a strong retention (recognition) response to the novel-colored "2" blocks. Infants tested with blocks showing an "A" on each face, however, gave a non-retention (discrimination) response after the delay, showing that the details of the mobile were encoded and could influence responding. This finding of discrimination performance eliminated the possibility that the infants in the novel-color group were simply generalizing after three days of training, and overall, this investigation showed that the operant procedure is capable of eliciting a categorical response even after a relatively long delay.

Serial Order

Tests of serial order appeared in the adult memory literature as early as Ebbinghaus (1964), and have elicited much scrutiny, but it was traditionally thought that infants younger than one year were not capable of this type of short-term memory. Gulya, Rovee-Collier, Galluccio, and Wilk (1998) examined this issue in 3- and 6-month-old infants using the mobile operant training approach. Infants were trained using a sequence of mobiles (ABC) each day for three days, and then tested to see which of the three would serve as an effective memory retrieval cue on the fourth day. If a 3- or 6-month-old infant was not cued prior to the test, mobile A was the best cue. If an infant received mobile A as a 1-min cue prior to the test, mobile B, but not C, elicited responding. If A and B were presented as cues, only mobile C functioned to cue infants' responding. These test groups demonstrate that this type of short-term memory is functioning in young infants and can be accessed through the use of an operant procedure.

Object Knowledge

A number of aspects of visual recognition of objects have been investigated using operant conditioning. Gerhardstein and colleagues have used the mobile procedure to test 3-month-old infants' ability, following training with various levels of viewpoint, to perceive the invariant (3D) form of an object. This was accomplished by training the infants to kick to move a computerized mobile (for details, see Kraebel et al., 2004) that controlled the range of motion of the objects on the mobile, and then testing for recognition with either the same view as presented during training, a novel view of the same object, or a novel object. Infants proved to be able to transfer training from a learned view to a novel view, for both simple (West, Kraebel, & Gerhardstein, 2005) and complex, multi-part (Kraebel & Gerhardstein, 2005) objects, but only when the range of views presented during training was sufficiently large. Restricted training ranges did not elicit recognition responses when novel views were presented during the test session.

Advantages of Operant Techniques in Examining Cognitive Concepts

The difficulty of conducting research into cognitive development with young infants is compounded by the limited types of response that they are capable of producing (Haith, 1998). Infants are simply not able to produce the linguistically-based responses that studies using adult participants typically rely on (e.g., "this object is a member of that category"). This lack of language limits researchers to non-verbal measures, predominantly "looking-time" procedures, as a means of assessing infants' understanding of their world. Investigations using standard looking-time procedures typically present an infant with a visual stimulus and then measure the amount of time spent looking at the stimulus over a series of infant-controlled trials. Once the infant has reached a pre-determined habituation criterion, a test stimulus is presented. An increase in looking time to the test stimulus is presumed to reflect renewed interest/attention and evidence of discrimination between the initial habituation stimulus and the test stimulus. Recently, a debate has emerged as to the type of inferences that can be drawn from looking-time data (Cohen, 2004; Mareschal, 2000). Haith (1998) argued that adult-centric cognitive constructs (such as "expectations", "representations", and "surprise") should not be invoked unless perceptual accounts are ruled out (but see Baillargeon, 2000; Spelke, 1998).

To illustrate this point, Wynn (1992) investigated 5-month-olds' understanding of simple addition and subtraction. In a "1+1" condition, infants were shown a doll that was subsequently hidden behind an occluding screen. Next, the infants saw a hand bringing a second doll into the infant's view, which was then placed behind the occluder (thereby adding one doll to the total). The occluder was removed, revealing either one doll or two dolls. Infants looked longer at the one doll outcome, presumably because they were surprised to see only one doll in this "1+1" condition. In the "2-1" condition, infants were initially shown two dolls that were subsequently hidden by an occluder. Infants then saw a hand remove one of the dolls from behind the occluder (thereby subtracting one doll from the total). The occluder was removed, leaving either one or two dolls. Infants looked longer at the two-doll outcome, again, presumably because they were surprised to see two dolls in this "2-1" condition. Wynn inferred from these looking-time data that young infants possess an understanding of numeric concepts.

The conclusion that 5-month-old infants have an understanding of simple mathematical operation may, however, be premature. Haith (1998) argued that the infants in Wynn (1992) could be responding to a perceptual mismatch to some initial sensory memory of the individual dolls prior to being hidden away from view. When the occluder was removed in the "1+1" condition revealing only one doll, the infants could have simply detected the mismatch between the sensory memory of two dolls and the actual perception of one doll. The mismatch resulted in an increase in looking times, but that increase was not necessarily due to an understanding of the "1+1" addition operation. Cohen and Marks (2002) argued that Wynn's findings could be better explained by a familiarity preference and a preference for a greater number of objects. These perceptual accounts offer a more direct explanation of Wynn's looking-time data without the need to posit the existence of the cognitive concept of numbers in young infants.

The use of operant learning techniques offers an advantage over the traditional looking time studies when assessing cognitive facilities. In traditional looking-time procedures, often only a few seconds separates the habituation phase from the test phase. Given such a brief time frame, sensory level responding may contribute to any observed differences in looking-time. In typical operant learning procedures, such as the mobile reinforcement procedure, infants' responding at test is not dependent on any immediate sensory-level changes between training and test because the infants are tested 24 hr after training. Thus, responses from the infants at test must be due to a long-term representation (therefore, not sensory level impressions) stored in memory. This represents a significant advantage of an operant procedure to assess a higher level cognitive concept, such as object knowledge, because it allows the experimenter, by manipulating an object's characteristics between training and test, to determine which characteristics make up the infant's memorial representation of that object (see Rovee-Collier & Gerhardstein, 1997).

It is important to recognize, however, that the issue of applying adult-centric cognitive constructs in young infants must be done cautiously in all paradigms, including operant-learning studies. Gewirtz and Pelaez-Nogueras (1992) argued that many researchers who use instrumental conditioning with infants inappropriately employ higher-level constructs such as "expectancies" to explain their data without careful consideration of well-established principles of reinforcement. Fagen, Morrongiello, Rovee-Collier, and Gekoski (1984) investigated expectancies in 3-month-olds using the mobile operant-learning procedure. Fagen et al.'s infants were trained and tested over four days to kick to move a crib mobile. Infants (in Exp. 1) were placed in one of three groups: AAAA in which infants were shown the same mobile across the four days; ABCD in which infants were shown a different mobile on each of the four days; and ABCA in which the infants were shown the same mobile only on the first and last day. The infants in AAAA steadily increased their kicking rate on each day, which has been well-documented. The infants in ABCD also increased their rate of kicking; they learned to "expect" a different mobile on each day, according to Fagen et al. (1984). The infants in ABCA did not show an increase in kicking on the fourth day. Fagen et al. (also Fagen, 1993) argued that the principles of reinforcement would have predicted a rise in response on the fourth day because mobile A was reinforced on the first day. Fagen et al. concluded that the mobile A on the last day violated infants' expectation of receiving a different mobile on each day and therefore the mobile failed to elicit a kicking response. (Fagen et al. replicated the findings in a second experiment using similar conditions but with 3 days of training.)

Gewirtz and Pelaez-Nogueras (1993) and Schlinger (1993), however, disputed Fagen's (1993) "expectancy" account. Gewirtz and Pelaez-Nogueras (1993) argued that Fagen invoked expectancy to explain the increased response observed in Fagen et al.'s (1984) ABCD group, but an increase in responding was also used to support the expectancy account. Schlinger (1993) observed that infants in the ABCD condition increased responding even after the first day of operant training. This could be interpreted under the expectancy account as showing that the infants already "expected" a different mobile on the second day, which would not be logical. Gewirtz and Pelaez-Nogueras (1993) also alluded to intermittent periods of reinforcement and nonreinforcement in Fagen et al.'s (1984) procedure that could explain the findings without invoking expectancy.

Ainsworth, Blehar, Water, and Wall's (1978) classic work on infant attachment offers another example of a study in which multiple interpretations may exist for the recorded data. The procedure in this investigation was to have the caretaker leave the infant alone in a room while the infant's level of discomfort was measured to infer the type of attachment present between parent and child (e.g., an insecure attachment). The problem according to Gewirtz and Pelaez-Nogueras (1992) is that this type of measure neglects the reinforcement history of the infant's distress response (e.g., the extent to which the infant's crying behavior is reinforced by the reappearance of the caretaker). The response of the infant may be unrelated to the type of attachment with the caretaker and may be better predicted by the schedule of reinforcement between infant and caretaker, thus alleviating the need to propose an attachment construct as an explanation of the distress response.

Given recognition of the caution needed in interpreting data aimed understanding cognitive concepts, the question then becomes, at what point would positing a cognitive construct in pre-verbal infants be appropriate? It is obvious that infants are on their way to becoming cognitively-based beings. Cognitive constructs, however, such as "expectation" are very different for infants, children, and adults; they increase in complexity over time. Haith (1998) emphasized the need for graded concepts of cognitive processes to better understand how these constructs develop (e.g., detecting mismatches between perception and memory leads to the development of detecting quantity changes, which at some point, leads to grasping of simple arithmetic operations). This approach will push research away from the dichotomous presence/absence of a cognitive construct, and toward addressing how constructs develop.

Use of Operant Techniques in Clinical Applications

Operant tasks have also been utilized to examine learning and memory in clinical populations. Ohr and Fagen (1991) examined the ability of 3-4-month-old infants with Down's syndrome to learn to kick for visual reinforcement (movement of a crib mobile) and to retain this learned response across a one-week retention interval. They found that infants with Down's syndrome were able to learn and retain the task at levels comparable to those of age-matched infants without Down's syndrome. Wishart (1991), using similar procedures and 1-24-month-old infants in a longitudinal design, found that as development progressed, infants with Down's syndrome utilized counterproductive learning behaviors; older infants showed a preference for reinforcing events generated randomly, and a decline in their contingent response rates. Wishart reported that this dependence on non-contingent reinforcement could be reduced, and the level of conditioned responding increased, by enhancing the success rate of early learning. This enhancement appeared to provide consolidation advantages for the infants' learning as well. Dunst, Cushing, and Vance (1985) applied an operant technique to examine the ability of profoundly retarded, multiply handicapped infants to learn to make specific head turns for visual reinforcement (a multicolored display). Their results showed that although the infants were able to show contingent learning, the use of physical prompts accelerated the acquisition of the response, particularly under conditions of free-operant responding.

Operant tasks have also been employed as diagnostic tools to assess sensory capabilities in infants. Clinical tests of hearing loss (Primus, 1987, 1988; Shaw & Nikolopoulos, 2004; Widen & Keener, 2003) are one such example. Visual reinforcement audiometry (VRA) is consistently used as a method to assess hearing levels in infants. The general procedure involves presenting auditory stimuli to the left or right of an infant's head and observing whether the infant turns their head in the appropriate direction to the sound. The head turn, in many cases is then reinforced with visual stimulation. With continued learning and reinforcement, discrimination between sounds is possible, allowing more detailed examination of hearing deficiencies.

Use of Operant Techniques for Testing Prenatal and Perinatal Infants

One area of particular interest in the context of potential clinical applications is the use of operant techniques to test learning and memory in extremely young infants, in particular, prenatal infants prior to their conceptual birth date. The literature contains only a few studies of this clinical population; they are reviewed in some detail as their potential utility for the development of future tests in extremely young infants is substantial.

Thoman and Ingersoll (1993) conducted what appears to be the only investigation of learning in premature infants using operant techniques. Note that the animal literature presents a more complete picture in terms of prenatal learning; for an example, see Smotherman (1982). Thoman and Ingersoll created a "breathing bear" toy, which inflated and deflated at a rate consistent with each individual infant's respiratory rate. The bear also provided potentially comforting tactile stimulation (fur), and previous work had confirmed that full-term infants preferred the breathing bear over a number of other stimuli. The experimenters found that premature infants (mean age 32 weeks at study onset) showed an operantly conditioned decrease in time to contact the breathing bear, relative to premature control infants, who showed an increase in time to contact a non-breathing bear. This finding corresponds well with that of an earlier study reporting that contingent stimulus presentation correlated with success of intervention in premature infants (Barnard & Bee, 1983), and suggests that operant conditioning may have therapeutic value in this population.

Several perinatal tests using operant procedures have been reported in the past 25 years (DeCasper & Carstens, 1981; DeCasper & Sigafoos, 1983; Floccia et al., 1997). These tests have applied the work of Lipsitt and colleagues (e.g., Simmons & Lipsitt, 1961) in developing operantly conditioned sucking tests. DeCasper and Sigafoos (1983) were able to train perinatal infants to suck to hear the sound of a heart beating, and demonstrated good learning using this procedure. The importance of selecting a stimulus with strong reinforcing valance, however, was underscored by a finding by DeCapser and Prescot (1984), who attempted to operantly train perinatal infants to respond preferentially to their father's voice over an unfamiliar male voice. Despite a demonstration that infants could discriminate between the two voices, the experimenters were unable to elicit a reliable conditioned response when using the father's voice as the reinforcer, suggesting that familiarity may play a role in determining the value of a stimulus as a reinforcer for young infants in the context of operant learning.

Conclusion

The use of operant techniques in the field of developmental psychology has enjoyed a long and fruitful history. It is important to recognize the contributions that operant procedures can offer across a wide area of study, including emotional/social development, perceptual development, learning and memory, and cognitive development. Finally, it is equally important to reemphasize the potential of operant techniques to provide assessment tools for both normal and clinical populations of infants and children.

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