

SCHEDULES OF COVARIATION IN RESEARCH AND PRACTICE: A REVIEW AND DISCUSSION

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Behavioral events in which responses and stimuli co-vary continuously are evaluated with schedules of covariation (SOCs), such as synchronous and conjugate schedules. Although many behaviors of social significance are maintained by SOC, the paucity of research on these schedules spans the basic-applied continuum. The purpose of this review is to describe emerging research on SOC and identify areas for future study and practice.

Keywords: conjugate; schedules of covariation; synchronous

Reinforcement schedules specify the dimension of a given target response (e.g., pressing a lever, running on a wheel), the dimension of a programmed consequent event (e.g., one food pellet, 30-s break from instructional tasks), and the contingency between the two. In the behavioral sciences, there is a rich tradition of studying behavior-environment relations using schedules with discontinuous response dimensions, reinforcer dimensions, or both (e.g., count-count schedules¹; Williams & Johnston, 1992). Such schedules (e.g., ratio, interval) involve episodic events with responses and reinforcers that are discrete, repeatable, and easy to count (Ferster & Skinner, 1957). By contrast, for other schedules, the dimensions of the response and reinforcer are not discrete, but rather involve continuous events wherein both responses and stimuli co-vary (e.g., duration-duration schedules). Here, a given dimension of a response (e.g., duration, amplitude) determines at least one dimension of the consequent stimulus at a moment-to-moment level (Williams & Johnston, 1992). These schedules are often referred to as schedules of covariation (SOCs). The current paper focuses on

the two primary SOC: synchronous and conjugate schedules.

In synchronous schedules, the onset/offset of the consequent event co-varies with the onset/offset of the target behavior (e.g., Hardesty et al., 2023). For example, a teacher might try to decrease out-of-seat-behavior in the classroom by arranging a contingency wherein some event such as preferred music plays continuously while a student remains seated, and terminate the music as soon as the student leaves their seat (e.g., Diaz de Villageas et al., 2020). In conjugate schedules, there is a continuous, proportional relation between some dimension of the target response (e.g., force, amplitude) and the consequent event. Dimensions of the consequent stimuli change based on moment-to-moment variations in responding. Examples include ambulating (e.g., Peterson et al., 2023), early developing operants (e.g., suckling; Lindsley, 1956), and various forms of repetitive and self-injurious behavior (see Rapp, 2008).

Despite their ubiquitous presence in the maintenance of socially relevant behaviors, it is unclear why SOC have not been studied more previously. One reason may be that these duration-duration schedules require complex experimental arrangements to systematically manipulate independent variable(s) and accurately measure dependent variable(s) of interest. Indeed, many of the studies included in the present review used sophisticated software and hardware which may have only recently become available as a result of advancements in

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¹ Count-count schedules the dimensions of both the response and consequent event are discontinuous. For

example, one lever press is followed by delivery of one food pellet (i.e., a fixed-ratio 1 schedule).

behavioral technology. Basic research on these SOCs has identified at least three important features that proffer them as useful and worthy of evaluation in translational and applied research. Namely, (a) responding is rapidly acquired by humans (e.g., MacAleese et al., 2015), (b) behavior under control of SOCs changes rapidly with changes in stimulus conditions (e.g., Falligant et al., 2018, 2020), and (c) SOCs maintain steady-state, level behavior (e.g., Deochand et al., 2020). In terms of their applied utility, SOCs are potentially useful for evaluating behavior-environment relations for which the response and reinforcer naturally covary, perceptual events serve as reinforcement for repetitive or continuous responses, or both (Rapp, 2008). However, despite their centrality to many naturally occurring and socially relevant behaviors, there is a relative paucity of research on these schedules. Thus, the purpose of this review is to describe contemporary research on SOCs, identify their applied usage, and highlight areas for future study and considerations for practice.

METHOD

The first author conducted a systematic search of three bibliographic databases (i.e., APA PsycArticles, APA PsycInfo, and Education Research Complete) including the following search term combinations: (a) “conjugate schedule,” OR “conjugate reinforcement” and (b) “synchronous schedule,” OR “synchronous reinforcement.” These search term combinations were repeated across all three databases. The search yielded 89 records. Returned results were limited to the following criteria: (a) peer-reviewed journals, (b) published between 2008 and 2024, (c) available in English, and (d) empirical studies that evaluated human behavior under control of an SOC. Articles currently under review, in-press, and preprints were included. We selected 2008 as the starting point for the search because this was when the most recent discussion article regarding SOCs was published (i.e., Rapp, 2008). In total, 18 articles met criteria for inclusion in the present review. The first and second authors extracted the following variables from each article: setting and participant characteristics (Table 1), and relevant

experimental details (Table 2). The second author assessed intercoder agreement by independently coding all 18 articles. We calculated intercoder agreement by dividing the total number of agreements by agreements plus disagreements. Agreement was 100% for all included articles. We begin with a description of articles which evaluated synchronous schedules organized into four broad areas for application: (a) adaptive classroom behavior, (b) mitigating disease transmission, (c) reinforcing efficacy of audiovisual stimulation, and (d) physical activity. Then, we describe and discuss three areas for application of conjugate schedules: (a) reinforcing efficacy of audiovisual stimulation, (b) extinction-induced variability, and (c) athletic performance.

RESULTS

Synchronous Schedules

Application #1: Promoting Adaptive Classroom Behavior. In a synchronous schedule, continuous access to a consequent stimulus is provided only when the response occurs continuously and at some specified criterion—access to the consequent stimulus ceases when the response no longer meets the specified criterion. Along this line, Diaz de Villegas et al. (2020) directly compared a synchronous reinforcement schedule to a correlated reinforcement schedule² in an “accumulated” condition for increasing on-task behavior among typically developing (TD) preschoolers. In the synchronous reinforcement condition, preferred music played continuously so long as the participant was engaged in on-task behavior (e.g., tracing). In the accumulated reinforcement condition, at the end of each session, music played for a duration of time yoked to the duration of on-task behavior displayed during the session. In subsequent concurrent-chains preference assessments, researchers found participants preferred the synchronous reinforcement condition relative to the accumulated reinforcement condition. Moreover, data indicated participants displayed

² In a correlated reinforcement schedule, the amount of reinforcement is contingent upon the sum of responses. For example, rotating the key of a windup toy produces some action of the toy which is equal to the sum of the

rotations. These should not be confused with *time-correlated* reinforcement schedules (Clark, 1959), which are also referred to as limited-hold (Ferster & Skinner, 1957) or temporally defined (Hearst, 1958) schedules.

Study	Experiment	SOC	Setting	Participants	<i>N</i>
Baruni et al. (2025)	1	Synchronous	Laboratory	Undergraduates	25
Cook et al. (2024)	1	Conjugate	Laboratory	Adults	81
Curiel et al. (2024)	1	Conjugate	Public School	Children (2 with ID)	7
Davis et al. (2021)	2	Conjugate	Laboratory	Undergraduates	54
Deochand et al. (2020)	1	Conjugate	Laboratory	Adults	8
Diaz de Villagas et al. (2020)	1	Synchronous	Preschool	Children	8
Falligant et al. (2018)	1	Conjugate	Laboratory	Undergraduates	6
Falligant et al. (2018)	2	Conjugate	Laboratory	Undergraduates	7
Falligant et al. (2018)	3	Conjugate	Laboratory	Undergraduates	5
Falligant et al. (2020)	1	Conjugate	Laboratory	Undergraduates	6
Falligant et al. (2020)	2	Conjugate	Laboratory	Undergraduates	4
Hardesty et al. (2022)	1	Synchronous	Remote (home)	Children	3

Study	Experiment	SOC	Setting	Participants	<i>N</i>
Leslie et al. (2023)	1	Synchronous	Center	Children (2 with ASD)	6
MacAleese et al. (2015)	1	Conjugate	Laboratory	Undergraduates	5
MacAleese et al. (2015)	2	Conjugate	Laboratory	Undergraduates	4
McHugh et al. (2022)	1	Synchronous	Remote (home)	Adults with IDD	5
Peterson et al. (2023)	1	Conjugate	Laboratory	Undergraduates	10
Popescu et al. (2021)	1	Synchronous	Laboratory	Infants	37
Pinkston et al. (2024)	1	Synchronous	Laboratory	Undergraduates	17
Rapp et al. (2025)	1	Synchronous	Laboratory	Undergraduates	60
Sheridan et al. (2024)	1	Conjugate	Laboratory	Undergraduates	98
Stordahl et al. (2023)	1	Synchronous	Varied	Children with ASD	4

Table 1. Settings and Participant Characteristics

Study	Experiment	Manipulandum	Response	Dimension	Consequent Event	Dimension
Baruni et al. (2025)	1	Manual treadmill	Walking	Speed (m/s)	Auditory stimulus	Volume
Cook et al. (2024)	1	Hand dynamometer	Squeezing handle	Force (kg)	Auditory stimulus	Volume
Curiel et al. (2024)	1	iPad	Pressing button	Rate	Audiovisual stimulus	Volume, Visual clarity
Davis et al. (2021)	2	Hand dynamometer	Squeezing handle	Force (kg)	Visual stimulus	Visual clarity
Deochand et al. (2020)	1	Punching bag	Punching	Force relative Newtons, Rate	Auditory stimulus	Volume, Speed
Diaz de Villagas et al. (2020)	1	Paper and pencil	Shape tracing	Duration On-Task	Auditory stimulus	Volume
Falligant et al. (2018)	1	Force transducer	Pressing knob	Force (g)	Audiovisual stimulus	Volume
Falligant et al. (2018)	2	Force transducer	Pressing knob	Force (g)	Audiovisual stimulus	Volume
Falligant et al. (2018)	3	Force transducer	Pressing knob	Force (g)	Audiovisual stimulus	Volume
Falligant et al. (2020)	1	Force transducer	Pressing knob	Force (g)	Audiovisual stimulus	Volume
Falligant et al. (2020)	2	Force transducer	Pressing knob	Force (g)	Audiovisual stimulus	Volume
Hardesty et al. (2022)	1	Keyboard/ mouse , manipulatives	Academic Task	Percentage Session On-Task	Auditory stimulus	Volume
Leslie et al. (2023)	1	Mask	Mask-wearing	Duration of Mask-Wearing	Audiovisual stimulus	Volume, Picture
MacAleese et al. (2015)	1	Keyboard	Key pressing	Interresponse time	Visual stimulus	Visual clarity

Study	Experiment	Manipulandum	Response	Dimension	Consequent Event	Dimension
MacAleese et al. (2015)	2	Keyboard	Key pressing	Interresponse time	Visual stimulus	Visual clarity
McHugh et al. (2022)	1	Mask	Mask-wearing	Duration of Mask Wearing	Audiovisual stimulus	Volume, Picture
Peterson et al. (2023)	1	Ergometer	Pedaling	Speed (Revolutions/s)	Audiovisual stimulus	Volume, Video clarity
Popescu et al. (2021)	1	Bracelets	Arm movement	Acceleration (g m/s ²)	Audiovisual stimulus	Volume and Light
Pinkston et al. (2024)	1	Manual treadmill	Walking	Speed (m/s)	Auditory stimulus	Volume
Rapp et al. (2025)	1	Manual treadmill	Walking	Speed (m/s)	Auditory stimulus	Volume
Sheridan et al. (2024)	1	Hand dynamometer	Squeezing handle	Force (kg)	Visual stimulus	Visual clarity
Stordahl et al. (2023)	1	Varied	Varied	Duration Engaged	Varied	Varied

Table 2. Experimental Details

higher levels of on-task behavior in the synchronous reinforcement condition.

In a similar study, Hardesty et al. (2023) compared the effects of synchronous schedules versus noncontingent stimulus delivery on on-task behavior among TD school-age children. Researchers used a concurrent-operants arrangement wherein participants could choose to engage in on-task (i.e., engaging with an academic task presented on a computer screen) or off-task (i.e., drawing) behavior. In the synchronous schedule condition, researchers only played music when the participant was on-task. In the noncontingent condition, the researcher played music when the participant engaged in on- and off-task behavior. On-task behavior occurred at higher levels in the synchronous condition, though participants preferred the noncontingent stimulus delivery condition. Researchers assessed condition preference using a concurrent-chains procedure similar to that described in Diaz de Villegas et al. (2020). Stordahl et al. (2023) subsequently extended this line of work by using synchronous schedules to improve targeted and nontargeted behaviors among four children with autism spectrum disorder. Target responses included proximity to others during social interactions, duration of sitting at a lunch table and duration of pedaling a bike trainer. Nontargeted response dimensions included frequency of approaches (to others or the lunch table) and pedaling speed. Reinforcers included audio and visual stimuli delivered across a variety of modalities (e.g., tablet, toys, mobile phone, radio, etc.). Consistent with the aforementioned studies, Stordahl et al., found targeted behaviors improved well above baseline levels for all four children. In addition, nontargeted behaviors (i.e., frequency of approaches to table, approaches to teacher) improved to above baseline levels for two of the four children.

Application #2: Promoting Mask Wearing to Mitigate Disease Transmission. McHugh et al. (2022) used synchronous schedules of reinforcement to increase mask-wearing among adults with intellectual and developmental disabilities (IDD). Mask-wearing was identified as a socially relevant target behavior which may decrease the transmission of COVID-19. Experimenters trained residential staff members via telehealth to deliver high-preference (HP) audio and visual stimulation (e.g., preferred movies and songs) contingent on mask-wearing. That is, once participants had securely placed

their masks over their ears, nose, and mouth, staff delivered continuous access to a preferred audiovisual stimulus. Experimenters increased the total duration of mask-wearing to a terminal goal of 30 min, with results that generalized to novel community environments for four of the five individuals. In a similar study, Leslie et al. (2023) successfully replicated and extended upon McHugh et al. by using the same procedures with six school-aged children, two of whom had an autism spectrum diagnosis. Researchers successfully increased mask-wearing to a terminal goal of 30 min and, for some participants, mask-wearing generalized to classroom environments across the school day.

Application #3: Assaying Human Preference and Reinforcing Efficacy of Audiovisual Stimulation. Behavior maintained by synchronous schedules appears to transition rapidly based on stimulus conditions, which makes these schedules useful for rapidly assaying preference for a variety of stimuli. For example, in a study by Popescu et al. (2021), researchers used synchronous schedules to quantify the acceleration properties of arm movement of infants for the purpose of understanding sensitivity to sensorimotor contingencies. Researchers applied smart bracelets that produced audiovisual stimulation to the wrists of infants and exposed two groups of participants to a contingent or noncontingent condition. For participants in the contingent condition, bracelets produced audiovisual stimulation when the infant's arm movement met a specified criterion. This criterion was progressively increased to a terminal criterion of 1.6 g m/s². For participants in the noncontingent group, audiovisual stimulation was yoked to the frequency of stimulation produced by infants in the contingent group. The distribution of stimulation frequencies was bimodal for the contingent group. Thus, researchers matched frequency of stimulation by sampling frequencies displayed by infants in the contingent group. Using this group design, researchers compared arm movement between groups and found infants in the contingent group displayed more arm movement than infants in the noncontingent group and this movement increased minute-to-minute for the duration of the experiment.

Application #4: Modulating Physical Activity. In a recent series of studies, researchers evaluated the walking speed of TD adults modulated through contingent access to music.

Pinkston et al. (2024) delivered HP music to participants when they altered their walking speed according to a range-bound changing criterion design. In this experiment, 17 participants were exposed to a five-component mixed schedule including baseline, synchronous, and extinction components which were 5 min each in duration. In the baseline component, HP music was delivered independent of responding. Across three synchronous components, participants could access HP music only when walking at a speed within the specified range and the range shifted across synchronous components. Walking speeds outside the range did not produce music. In the third synchronous component, the range-bound criterion tightened such that less variability in walking speed would contact reinforcement. In the extinction component, no music was delivered. Findings indicated 14 of 17 participants demonstrated schedule control (i.e., walking speed within the specified range for 50% or more of the duration of the synchronous component) and up to 70% of those participants also demonstrated extinction-induced variability. Importantly, the authors noted this was a strong demonstration of walking intensity as an operant behavior and that variability in walking intensity could be modulated using a range-bound changing criterion design. Moreover, the findings demonstrated synchronous schedules could be used to produce moderate to vigorous levels of physical activity.

Baruni et al. (2025) extended these findings by implementing non-overlapping ranges within synchronous schedule components in a similar five-component mixed schedule. Specifically, during synchronous components, the ranges of walking speeds that produced access to HP music did not contain any equivalent values across components such that participants were required to make substantial changes in walking speed across components. Results indicated that 18 of 25 participants demonstrated schedule control. Note, this is slightly less than the percentage of participants who demonstrated schedule control in the Pinkston et al. (2024) study. The authors attribute this difference in part to more effortful behavior change as the reinforcement requirements were substantially different across synchronous components with non-overlapping ranges. Rapp et al. (2025) used a similar experimental design to demonstrate positive reinforcement was more effective for

producing schedule control versus negative reinforcement.

Similar to the first two studies, Rapp et al. (2025) implemented a five-component mixed schedule with baseline, synchronous, and extinction components in a range-bound changing criterion design. Participants were assigned to HP or low-preferred (LP) music conditions. For 30 participants assigned to the HP music condition, walking speeds within range produced the HP music (i.e., synchronous positive reinforcement). For 30 participants assigned to the LP music condition, walking speeds within the specified range removed the LP music (i.e., synchronous negative reinforcement). Data indicated 66.7% of participants in the HP music condition demonstrated schedule control as compared to only 43.33% of participants in the LP music condition. Statistical analyses indicated participants in the HP music condition walked significantly faster than participants in the LP music condition across synchronous and extinction components. Taken together, findings from these three studies demonstrate the utility of synchronous schedules for modulating physical activity, allowing for shifts in speed, variability, and reinforcement contingencies. As noted by Baruni et al. (2025), this versatility is especially important for high-effort, multidimensional behaviors.

Conjugate Schedules

Application #1: Assaying Reinforcing Efficacy of Audiovisual Stimulation. A number of recent studies have explored the use of conjugate schedules for assaying the reinforcing efficacy of visual (MacAleese et al., 2015) and audiovisual (Falligant et al., 2018) stimuli. MacAleese et al. (2015) evaluated key pressing among undergraduates conjugately reinforced or punished by changes in clarity of an image presented on a computer screen. Findings from Experiment 1 indicated participant responding shifted rapidly in response to changes in the intensity of clarity changes produced by their response, an important feature of conjugate schedules. In addition, results from Experiments 2 and 3 indicated participants' responding decreased in extinction and conjugate punishment phases, respectively.

Falligant et al. (2018) extended upon findings from MacAleese et al. (2015) by responding on a force transducer that was conjugately reinforced by changes in the volume of audiovisual stimuli

with undergraduate participants. After demonstrating that responding was sensitive to changes in intensity of volume on a conjugate schedule (Experiment 1), they found that HP audiovisual stimuli were more conjugately reinforcing than LP stimuli (Experiment 2).

Recently, Curiel et al. (2024) used conjugate schedules to evaluate reinforcing effects of videos among school aged children, two of whom were diagnosed with an intellectual disability. First, researchers identified HP and LP videos for each participant. Then, they evaluated reinforcing effects of videos using a concurrent-chains arrangement with conjugate schedules. To begin the concurrent-chains preparation, the participant selected a video from an array of three thumbnails on a tablet screen (LP video, HP video, and a black screen control). Then, in the terminal link, button pressing at or above a rate of two responses per second played the video at 100% volume and 100% clarity. When button pressing decreased below this criterion, the volume and clarity of the video decreased progressively by 25%, for each second in which this criterion was not met, until 4 s elapsed without meeting criteria. Rate of button pressing in the conjugate reinforcer assessment demonstrated correspondence with the preference assessment for five of seven participants. This study further demonstrates the utility of SOCs for efficiently evaluating reinforcing effects of stimuli.

Similarly, Davis et al. (2021) evaluated responding on a hand dynamometer among undergraduates in a progressive conjugate preparation. First, they conducted a multiple stimulus without replacement preference assessment (MSWO; DeLeon & Iwata, 1996) to identify and rank order preference for five images. Then, experimenters presented the images on screen and participants were instructed to apply force to a hand dynamometer to maintain clarity of the image. Each second, the force required to maintain the image at 100% clarity increased. If the participant did not apply force sufficient to meet the changing criterion, the image reduced in clarity by 10% each second until it became 100% transparent. They subsequently quantified the correspondence between preference rankings, based on MSWO data, and the ranked mean or peak force exerted in the progressive conjugate preparation. Based on Chi-square tests of independence, results indicated strong correspondence between MSWO rank order and both mean and peak force

rank order. This finding has since been replicated with other samples of undergraduates (Sheridan et al., 2024). In addition, Cook et al. (2024) replicated these procedures using auditory stimuli and demonstrated strong correspondence between MSWO rank order and mean and peak force rank order. Given the progressive nature of the task, as illustrated by the equations described in Sheridan et al., these researchers conceptualize this preparation as a form of preference assessment. That is, much like traditional reinforcer assessment methods, persistence in responding in the presence of increasing response requirements may be interpreted as a measure of relative reinforcing efficacy. Taken together, this series of studies suggests that conjugate schedules can be used to assay human preference for audio and visual stimuli effectively and efficiently.

Application #2: Studying Extinction-Induced Variability and Behavioral Persistence. In Falligant et al. (2018; Experiment 3), experimenters introduced a two-component mixed schedule to examine response persistence during extinction following conjugate reinforcement. Their results suggested that responding in conjugate schedules (a) shifts rapidly with changes in the environment and (b) produces extinction-induced variability in responding, similar to discontinuous schedules of reinforcement. To extend upon these findings, Falligant et al. (2020) used a similar preparation to examine response force during extinction following either dense or lean periods of conjugate reinforcement. This was accomplished by manipulating force multiplier values associated with the target response (Experiment 1). They found that response force was greater in extinction components following conjugate components with low force-multiplier values (i.e., leaner reinforcement) as compared to components with high force-multiplier values (i.e., denser reinforcement). Next, participants experienced response-independent delivery of the HP audiovisual stimulus or response-dependent, conjugately reinforced delivery of the HP audiovisual stimulus, followed by subsequent extinction components. Results from four participants indicated that mean response force was higher in the extinction component following the response-independent reinforcer delivery condition. Taken together, findings from these experiments indicated responding in conjugate schedules is rapidly acquired, sensitive to changes in stimulus conditions, and

modulated by the correspondence of response-reinforcer relations vis-à-vis different force multiplier coefficients.

More recently, Peterson et al. (2023) evaluated the effect of inaccurate versus accurate rules on behavior maintained by a conjugate schedule. In this study, experimenters first identified HP audio and visual stimulation and evaluated baseline levels of pedaling an ergometer. In the 1-min baseline component, the researcher instructed the participant to pedal on an ergometer for 60 s and delivered praise at the end of the component. Then, experimenters used a multiple schedule and exposed participants to (a) a conjugate reinforcement component or (b) an extinction component. Each component was 60 s in duration with 3-s blackouts between components and the total duration of combined components was 22 min. In the conjugate condition, pedaling at or above baseline levels produced 100% clarity in audiovisual stimulation and no static. Pedaling below baseline levels produced proportionately less clear audiovisual stimulation (i.e., more static). In the extinction component, pedaling at any level did not alter static on the screen. Researchers instructed participants in the accurate rules group to pedal only if pedaling improved stimulus clarity and to stop pedaling if it did not. Researchers instructed participants in the inaccurate rules group to continue pedaling even if pedaling did not improve stimulus clarity.

Findings indicated that schedule control emerged for participants in the accurate rules group, but not in the inaccurate rule group. That is, participants in the accurate rule group (a) maintained responding at or above baseline levels in the conjugate components and (b) decreased responding in the extinction components to at or near-zero levels. In addition, participants in the accurate rule group displayed increased levels of pedaling in the conjugate components following extinction components, indicating an apparent establishing operation for the HP stimulus. Participants in the inaccurate rule group (a) did not tend to respond at or above baseline levels in conjugate components and (b) demonstrated undifferentiated responding across conjugate and extinction components (i.e., no decrease in responding during extinction components).

Application #3: Improving Athletic Performance. Deochand et al. (2020) used an audiovisual intervention to examine punching

speed and force among adult boxers. For each participant, speed of punching a punching bag was conjugately reinforced by HP music speed and punching force was conjugately reinforced by music volume. When participants met the criterion for punching speed HP music played at an appropriate tempo and a feedback screen turned green. Specifically, if participants punched at a speed below the criterion, the music played at a faster tempo and the feedback screen turned red. When participants met the criterion for punching force, HP music played audibly. If participants did not meet the criterion for punching force, the HP music played at a volume that reduced progressively across time. Across eight participants, punching speed and force increased for five in the conjugate audiovisual intervention phase.

DISCUSSION

Although many behaviors of social relevance are apparently maintained by SOCs, this review revealed that a relative paucity of research exists regarding these schedules. Thus, the purpose of this review was to describe emerging research on schedules of covariation and identify areas for future study and considerations for practice. We organize these recommendations along common themes.

Recommendation #1: Reinforcing Adaptive Variability

Importantly, synchronous schedules were demonstrated to be useful for reinforcing moment-to-moment variations in behavior within a desired range, across a variety of adaptive behaviors. Pinkston et al. (2024) directly evaluated this phenomenon using the range-bound changing criterion design by decreasing the range between the upper and lower criteria in one of the synchronous components. This findings was extended by Baruni et al. (2025) and Rapp et al. (2025). In addition, for some of the behaviors targeted for intervention by Stordahl et al. (2023) some degree of variation may be allowable or even desirable, such as students varying their proximity to peers. Previous research has conceptualized variability as an operant behavior described as “a continuum ranging from repetitive at one end to stochastic at the other” (Neuringer 2002, p. 672). Indeed, variability may include fluctuations in topographical (e.g., Baruni et al., 2014) or dimensional quantities (e.g., Blough, 1966) which may be important for contexts in which it is

desirable to modulate a multidimensional behavior. Moreover, when operant variability allows an organism to optimize reinforcement or avoid aversive stimulation, it may be considered adaptive variation (Silbaugh et al., 2021).

Thus, we recommend future research evaluate the utility of synchronous schedules in contexts in which fluctuations in the target behavior are adaptive. For example, the experimental conditions used with manually-powered treadmills and ergometers could be extended to stationary cycling or rowing. As it relates to classroom behaviors, the procedures used by Diaz de Villegas et al. (2020) could be extended to other behaviors for which topographical variability is allowable. For example, it may be appropriate to use synchronous schedules to reinforce remaining in an assigned area such as a carpet square wherein a variety of sitting behaviors are appropriate (e.g., sitting criss-cross, kneeling, squatting). Moreover, to our knowledge, synchronous schedules have not yet been evaluated in group contingencies. For example, access to HP music delivered synchronously contingent upon all students in a classroom engaging in on-task behavior or some acceptable range of conversational volume.

Recommendation #2: Exploring Extinction-Induced Variability

Several studies included in this review directly or indirectly evaluated extinction-induced variability using conjugate (e.g., Falligant et al., 2020; Peterson et al., 2023) or synchronous (e.g., Baruni et al., 2025; Pinkston et al., 2024; Rapp et al., 2025) schedules. Falligant et al. (2020) found participants demonstrated greater extinction-induced variability following (a) conjugate components with low force-multiplier values versus high force-multiplier values and (b) response-independent conditions versus response-dependent conditions. In addition, across the series of studies using manually-powered treadmills (i.e., Baruni et al., 2025; Pinkston et al., 2024; Rapp et al., 2025), researchers reported anywhere from 52% to 80% of participants who demonstrated schedule control subsequently demonstrated extinction-induced variability following synchronous positive reinforcement. These findings suggest both antecedent (e.g., mixed versus multiple schedules) and consequent (e.g., schedule density) stimuli may affect extinction-induced variability.

Together, these studies demonstrate the utility of SOCs for studying extinction-induced variability. Moreover, it is unclear if features of SOCs may affect extinction-induced variability in ways different from discontinuous schedules. Thus, future research should continue to evaluate features of SOCs which may affect extinction-induced variability in multidimensional behaviors. For example, future research should extend evaluations of parameters of response-contingent consequent stimulus modulation (e.g., force multipliers) and the effect of antecedent stimuli (e.g., multiple versus mixed schedules).

Recommendation #3: Assaying the Effect of Antecedent Stimuli

Only one study included in the present review specifically evaluated rules as an independent variable. Peterson et al. (2023) found most participants in the accurate rules group demonstrated schedule control as compared to no participants in the inaccurate rules group. However, this study implemented a multiple schedule and did not include a control condition. Thus, the extent to which the rules or other antecedent stimuli may have affected responding is unclear. By contrast, all three studies evaluating the effect of synchronous schedules on walking speed implemented mixed schedules (i.e., Baruni et al., 2025; Pinkston et al., 2024; Rapp et al., 2024). Thus, it is possible that the percentage of participants who demonstrate schedule control may improve if multiple schedules were used instead.

Given instructions are typically provided to participants in these experimental preparations, future research should evaluate the effect of rules on behavior under control of SOCs. Peterson et al. (2023) indicated their accurate rule may be considered a "track" (Kissi et al., 2017). Consistent with this conceptualization, the extent to which participant responding demonstrates schedule control (or lack thereof) may reflect an individual's tracking or pliance repertoire. Future research should further explore the effect of antecedent stimuli on behavior under control of SOCs and how this might correspond to other repertoires.

Recommendation #4: Improved Technological Descriptions

In our review of the current literature on SOCs, particularly studies using synchronous and conjugate schedules, we found many researchers implemented features of both schedules at once.

For example, Davis et al. (2021) refer to their preparation as a conjugate schedule. As described, when participants ceased responding at criterion, clarity of the visual stimulus decreased disproportionately to responses below criterion. That is, responding below criterion did not maintain the consequent event in a sustained manner. Moreover, the authors describe the criterion to maintain clarity as the visual stimulus increased each second. Both Cook et al. (2024) and Sheridan et al. (2024) describe similar progressive conjugate schedules. Importantly, the equations described by Sheridan et al. further elaborate on the nature of the schedule. That is, the schedule included a floor level of clarity, such that some rapidly diminishing clarity of the image was available in the absence of responding (i.e., response-independent).

Similarly, Curiel et al. (2024) describe a schedule in which responding below the specified criterion of two button presses per second resulted in programmed decreases in volume and clarity disproportionately to responding below criterion. Moreover, the video appeared at 100% volume and clarity when responding occurred at criterion. That is, volume and clarity did not continue to increase proportionately as rate of responding increased. By definition, in a conjugate schedule, lower magnitude of response should maintain the visual stimulus at some proportionately diminished clarity (and vice versa). Thus, we view these studies as using features of both synchronous and conjugate schedules. As research in this area continues to expand, we hope consistency in terminology will enhance our understanding of these schedules and their applications. To that end, we provide an overview of the features of schedules as described by each study in Table s1 (See Supplemental File). By doing so, we hope to facilitate improved technological description of SOCs in future studies.

SUMMARY

Behavior-environment relations are typically evaluated using a variety of discontinuous schedules (e.g., ratio, interval) wherein the response and stimulus are characterized as separate, discrete events. By contrast, non-discrete, continuous events are characterized as relations wherein response and stimulus co-vary and are best evaluated through SOCs (viz., conjugate, correlated, and synchronous

reinforcement schedules). Overall, the current literature on SOCs demonstrates their utility in understanding and addressing behaviors of social relevance. Moreover, commonly used experimental preparations involve (a) response topographies which are rapidly acquired by humans and (b) manipulanda which are easily modified across a variety of independent variables. Given these qualities, we believe this area of research is ripe with opportunity for future study. We hope this review will serve to encourage such future endeavors as doing so will improve the impact of our science in understanding human behavior.

REFERENCES

- Baruni, R. R., Cook, J. L., Pinkston, J. W., Rapp, J. T., Miltenberger, R. G., Walker, E., Deshmukh, S., & Tai, S. (2025). Schedule control with a synchronous reinforcement treadmill preparation: A replication and extension. *Journal of Applied Behavior Analysis*, 58(2), 422–432. <https://doi.org/10.1002/jaba.70008>
- Baruni, R. R., Rapp, J. T., Lipe, S. L., & Novotny, M. A. (2014). Using lag schedules to increase toy play variability for children with intellectual disabilities. *Behavioral Interventions*, 29(1), 21–35. <https://doi.org/10.1002/bin.1377>
- Blough, D. S. (1966). The reinforcement of least-frequent interresponse times. *Journal of the Experimental Analysis of Behavior*, 9, 581–591. <https://doi.org/10.1901/jeab.1966.9-581>
- Curiel, H., Curiel, E.S., Villanueva, S., Ayala, C., & Cadigan, A. (2024). The multiple-stimulus-without-replacement preference assessment tool and its predictive validity. *Journal of Applied Behavior Analysis*, 57(1), 226–235. <https://doi.org/10.1002/jaba.1037>
- Davis, W. T., Rapp, J. T., Brogan, K. M., Pinkston, J. W., & Chinnappan, B. (2021). Comparing stimulus preference and response force in a conjugate preparation. *Journal of the Experimental Analysis of Behavior*, 116(1), 96–113. <https://doi.org/10.1002/jeab.705>
- DeLeon, I. G., & Iwata, B. A. (1996). Evaluation of a multiple-stimulus presentation format for assessing reinforcer preferences. *Journal of Applied Behavior Analysis*, 29(4), 519–533. <https://doi.org/10.1901/jaba.1996.29-519>
- Deochand, N., Costello, M. S., & Fuqua, R. W. (2020). Real-time contingent feedback to enhance punching performance. *The Psychological Record*,

- 70, 33–45. <https://doi.org/10.1007/s40732-019-00357-2>
- Diaz de Villegas, S. C., Dozier, C. L., Jess, R. L., & Foley, E. A. (2020). An evaluation of synchronous reinforcement for increasing on-task behavior in preschool children. *Journal of Applied Behavior Analysis*, 53(3), 1660–1673. <https://doi.org/10.1002/jaba.696>
- Falligant, J. M., Rapp, J. T., Brogan, K. M., & Pinkston, J. W. (2018). Response force in conjugate schedules of reinforcement. *The Psychological Record*, 68, 525–536. <https://doi.org/10.1007/s40732-018-0298-8>
- Falligant, J. M., Rapp, J. T., Brogan, K. M., & Pinkston, J. W. (2020). Extinction and response force in conjugate schedules. *The Psychological Record*, 70, 109–121. <https://doi.org/10.1007/s40732-020-00374-6>
- Ferster, C. B., & Skinner, B. F. 1. (1957). Schedules of reinforcement. Appleton-Century-Crofts.
- Hardesty, E. M., Lerman, D. C., & Hardee, J. L. (2023). A comparison of synchronous and noncontingent stimulus delivery on task engagement. *Journal of Applied Behavior Analysis*, 56(3), 664–673. <https://doi.org/10.1002/jaba.986>
- Leslie, S. C., Dozier, C. L., Kamlowksy, M. E., McHugh, C. L., Diaz de Villegas, S. C., & Kanaman, K. C. (2023). Using synchronous reinforcement to increase mask wearing in young children: A replication and extension. *Behavioral Interventions*. Advance online publication. <https://doi.org/10.1002/bin.1985>
- Lindsley, O. R. (1956). Operant conditioning methods applied to research in chronic schizophrenia. *Psychiatric Research Reports*, 5, 118–139. <https://psycnet.apa.org/record/1957-06429-001>
- MacAleese, K. R., Ghezzi, P. M., & Rapp, J. T. (2015). Revisiting conjugate schedules. *Journal of the Experimental Analysis of Behavior*, 104(1), 63–73. <https://doi.org/10.1002/jeab.160>
- McHugh, C. L., Dozier, C. L., Diaz de Villegas, S. C., & Kanaman, N. A. (2022). Using synchronous reinforcement to increase mask wearing in adults with intellectual and developmental disabilities. *Journal of Applied Behavior Analysis*, 55(4), 1157–1171. <https://doi.org/10.1002/jaba.950>
- Neuringer, A. (2002). Operant variability: Evidence, functions, and theory. *Psychonomic Bulletin & Review*, 9, 672–705. <https://doi.org/10.3758/BF03196324.10.3758/BF03196324>
- Peterson, M. C., Ghezzi, P. M., & Rapp, J. T. (2023). Multiple schedules of conjugate reinforcement and extinction: A translational model for assessing automatically reinforced behavior. *Journal of Applied Behavior Analysis*. Advance online publication. <https://doi.org/10.1002/jaba.1052>
- Pinkston, J. W., Cook, J. L., Baruni, R. R., Rapp, J. T., Deshmukh, S., & Miltenberger, R. G. (2024). Application of synchronous music reinforcement to increase walking speed: A novel approach for training intensity. *Journal of the Experimental Analysis of Behavior*, 122(3), 362–374. <https://doi.org/10.1002/jeab.4219>
- Popescu, S. T., Dauphin, A., Vergne, J., & O'Regan, J. K. (2021). 6-Month-old infants' sensitivity to contingency in a variant of the mobile paradigm with resolution in the laboratory. *Frontiers in Psychology*, 12. <https://doi.org/10.3389/fpsyg.2021.610002>
- Rapp, J. T. (2008). Conjugate reinforcement: A brief review and suggestions for applications to the assessment of automatically reinforced behavior. *Behavioral Interventions: Theory & Practice in Residential & Community-Based Clinical Programs*, 23(2), 113–136. <https://doi.org/10.1002/bin.259>
- Rapp, J. T., Baruni, R. R., Walker, E., Cook, J. L., Pinkston, J. W., Miltenberger, R. G., ... & Sheridan, D. J. (2025). Using high-preference and low-preference music in a synchronous reinforcement treadmill preparation: A further extension. *Journal of the Experimental Analysis of Behavior*, 124(1), e70026. <https://doi.org/10.1002/jeab.70026>
- Sheridan, D. J., Rapp, J. T., Edgemon, A. K., & Pinkston, J. (2024). Assessing stimulus preference using response force in a conjugate preparation: A replication and extension. *Journal of the Experimental Analysis of Behavior*, 122(1), 25–41. <https://doi.org/10.1002/jeab.926>
- Silbaugh, B. C., Murray, C., Kelly, M. P., & Healy, O. (2021). A systematic synthesis of lag schedule research in individuals with autism and other populations. *Review Journal of Autism and Developmental Disorders*, 8, 92–107. <https://doi.org/10.1007/s40489-020-00202-1>
- Stordahl, S. K., Cihon, J. H., Alai-Rosales, S., & Rosales-Ruiz, J. (2023). Increasing socially significant behaviors for children with autism using synchronous reinforcement. *Education Sciences*, 13(7), 751. <https://doi.org/10.3390/educsci13070751>
- Williams, D. C., & Johnston, J. M. (1992). Continuous versus discrete dimensions of reinforcement schedules: An integrative analysis. *Journal of the Experimental Analysis of Behavior*, 58(1), 205–228. <https://doi.org/10.1901/jeab.1992.58-205>