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ORIGINAL ARTICLE

Response Force in Conjugate Schedules of Reinforcement

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Abstract

In conjugate schedules of reinforcement, the amplitude or intensity of a reinforcing event is proportional to an aspect of the target behavior or response (e.g., MacAleese, Ghezzi, & Rapp, *Journal of the Experimental Analysis of Behavior, 104*, 63–73, 2015). In a novel series of experiments, MacAleese et al. demonstrated that changes in clarity of a visual stimulus conjugately reinforced an arbitrary target response in a sample of undergraduates. In Experiment 1, we extended the results from MacAleese et al. (2015) by evaluating whether different parameters of response-contingent volume change in audiovisual stimuli conjugately reinforced responses on a force transducer in a sample of undergraduates. In Experiment 2, we evaluated the degree to which responding was maintained when conjugate changes in the volume of audiovisual stimuli (either high-preferred or low-preferred) were provided as a consequence for exerting force on the manipulandum. In Experiment 3, we evaluated the degree to which responding was maintained across multiple extinction components. Results from these experiments indicate response force covaries with changes to the amount of force required to produce conjugate changes in audiovisual stimulation. Furthermore, results suggest force may be an important index of response effort and preference across low-and-high preferred stimuli within this conjugate schedule framework, as well as an important index of extinction-induced variability.

Keywords Conjugate reinforcement · Force · Stimulus preference · Extinction · Translational research

In conjugate schedules of reinforcement, the amplitude or intensity of a reinforcing event is proportional to an aspect of the target behavior or response (see Rapp, 2008). Under these continuous schedules, changes in the target responses covary with features of the consequent stimuli (e.g., Williams & Johnston, 1992). Many human activities include features of conjugate schedules, including stereotypic behavior, walking, crawling, singing and driving (e.g., pressing the accelerator on a vehicle quickly and forcefully produces a higher magnitude stimulus change than pressing the accelerator slowly and softly; Rapp, 2008; Williams & Johnston, 1992). Conjugate reinforcement procedures have been used to evaluate individuals' preferences for a variety of audiovisual stimulation (e.g., Switzky & Haywood, 1973), and these schedules may hold important implications in the study of automatically reinforced behavior (Rapp, 2008). Of late, translational work by MacAleese, Ghezzi, and Rapp (2015) sought to highlight the importance of continued analysis of these schedules.

In a series of experiments, MacAleese et al. (2015) evaluated whether changes in clarity of a visual stimulus contingent upon responding conjugately reinforced key pressing and examined the degree to which key pressing was acquired and maintained following conjugate reinforcement, conjugate punishment, and extinction. In Experiment 1, participants sat in front of a computer screen with a preferred picture that was obscured 100% by a white image. Depending on the condition of the seven-component multiple schedule arrangement they were in, key pressing produced concomitant 1%, 2%, 5%, 10%, 20%, 25%, or 50% increase in picture clarity. Results indicated that participants displayed lower mean rates of key pressing as the percentage of clarity change in the images increased. In Experiment 2, key pressing in the conjugate reinforcement condition produced a 5% increase in picture clarity and key pressing the extinction condition did not result in any changes to the picture clarity. Results from Experiment 2 demonstrated that participants acquired and maintained key pressing during the conjugate reinforcement condition and engaged in very low levels of responding by the end of the extinction conditions. Finally, in Experiment 3, key pressing

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in the conjugate reinforcement condition was compared to key pressing in the conjugate negative punishment condition, in which pictures were presented at maximum clarity and key pressing resulted in a 5% decrease in picture clarity. Results from this experiment showed that participants emitted high, steady rates of responding in the conjugate reinforcement condition and much lower, more variable rates of key pressing in the conjugate negative punishment condition.

Overall, MacAleese et al. (2015) demonstrated that changes in clarity of a visual stimulus can be used effectively in a conjugate-reinforcement experimental preparation. However, MacAleese et al. did not evaluate the extent to which nonpreferred visual stimuli maintained responding under conjugate reinforcement schedules. It should be noted that, across a variety of schedules, there tends to be a robust relation between relative preference and reinforcer effectiveness (e.g., Lee, Yu, Martin, & Martin, 2010; Piazza, Fisher, Hagopian, Bowman, & Toole, 1996), such that higher-preferred stimuli are typically more effective reinforcers than low-preferred stimuli. However, under specific schedule arrangements (e.g., single-schedules), low-preference (LP) stimuli may effectively serve as reinforcers (e.g., Glover, Roane, Kadey, & Grow, 2008). Though currently unknown, it is possible that LP stimuli, within conjugate schedules, may effectively maintain responding. Indeed, extant literature suggests unique schedules associated with reinforcer assessment preparations, including conjugate preparations, can moderate the reinforcing efficacy of stimuli.

For example, Williams and Johnston (1992) demonstrated that variations in both response and reinforcer dimensions (e.g., discrete vs. continuous) can result in differences in patterns of performance using preferred stimuli. Williams and Johnston compared continuous and discontinuous dimensions of count and duration reinforcement and responses in a sample of 41 undergraduate students. Four separate schedules were constructed: (a) count–count schedules, in which the response count was related to the reinforcement count; (b) duration–duration schedules, in which response duration was related to the duration of reinforcement; (c) count–duration schedules, in which the response count was related to the duration of reinforcement; and (d) duration–count, in which the response duration was related to the count of reinforcement. Participants were presented with a plastic wheel and instructed to turn it—depending on the particular experimental condition they were in (e.g., count–count schedule condition), reinforcement was provided contingent on engaging in the target response along the appropriate dimensions. Under the duration–duration schedule, there was covariation in the response–reinforcer relationship, constituting a conjugate schedule of reinforcement. An analysis and comparison of schedule arrangements demonstrated that both response duration and the percentage of session spent responding were greater with duration–count and duration–duration schedules than schedules that used response count. Thus, differences in the reinforcing efficacy of stimuli may be moderated by the response–reinforcer dimensions used in the reinforcer assessment preparation (e.g., Glover et al., 2008; Williams & Johnston, 1992). Thus, it is unclear if responding would have maintained with LP pictures in the conjugate preparation used by MacAleese et al., so additional research is needed to better evaluate the reinforcing value of high-preference (HP) and LP stimuli in conjugate reinforcement contexts. That is, research should examine if there are differences in the degree to which HP and LP stimuli conjugately reinforce responding within conjugate preparations.

Conjugate preparations are well-suited for evaluating the reinforcing efficacy of stimuli because conjugate preparations require an ongoing response to maintain access to reinforcing stimuli and allow researchers to evaluate responding across numerous parameters of each stimulus event (Rapp, 2008). However, more work is needed to evaluate how LP and HP stimuli function as reinforcers in conjugate schedules, particularly as a function of varying response effort. Indeed, LP stimuli may maintain responding when response requirements are low (e.g., fixed ratio [FR] 1), though HP stimuli may be more effective reinforcers under larger response requirements (e.g., a FR 20; Glover et al., 2008; Roane, 2008). Though FR schedules are frequently used to evaluate response effort in behavior–analytic preparations (e.g., Foster & Hackenberg, 2004; Hursh, Raslear, Shurtleff, Bauman, & Simmons, 1988), including progressive ratio schedules (e.g., DeLeon, Frank, Gregory, & Allman, 2009; Glover et al., 2008; Roane, 2008), force requirements have also been used to manipulate the effort of response requirements (Pinkston & McBee, 2014). That is, the force with which an individual emits a response may vary across and within schedules of reinforcement.

For example, Pinkston and McBee (2014) trained rats to earn sucrose by pressing an isometric force transducer on a FR-10 or FR-20 schedule. For all subjects, increasing the FR schedule requirement reduced the maximum force exerted during a response. In addition, response force decreased immediately following reinforcers and increased with continued responding. Thus, response force may vary as a function of work requirements, the FR position, or both. In other words, response force, and not the number of responses emitted on FR schedules, could be a more sensitive index of response effort than the number of responses emitted on FR schedules alone. Furthermore, Hursh et al. (1988) demonstrated that, under FR schedules, increasing response effort by adding weights to response levers tends to decrease reinforcer consumption. That is, varying the force required to emit a target response modifies the economic "cost" of that response.

Though response force has been studied along dimension of FR reinforcement schedules, the utility of assessing force under conjugate schedules is unknown. Given that force might be an important index of response effort (Pinkston & Libman, 2017; Pinkston & McBee, 2014), and variations in force requirements for responding modify the reinforcing value of stimuli (Hursh et al., 1988), it is reasonable to posit that force may serve as an important dimension of response effort in the assessment of HP and LP stimuli in conjugate schedules. Force is a continuous dimension, much like duration, whereas count is a discrete dimension. So, response effort, measured via response force, could be used to investigate continuous dimensions important in conjugate schedules, whereas count is inappropriate as a continuous dimension. In other words, given the aforementioned differences between count and duration contingencies (e.g., Williams & Johnston, 1992), it is worth considering how continuous dimensions affect conjugate contingencies. Given that stimuli that maintain responding under larger response requirements are more likely to function as reinforcers in other contexts (Roane, Lerman, & Vorndran, 2001), it might be useful for researchers to determine if differences in reinforcing efficacy of HP and LP stimuli exist across parameters of response effort in conjugate schedules. Thus, the purpose of the current project was to evaluate the utility of a novel preparation using a force-transducing apparatus for assessing the conjugate-reinforcing value of audiovisual stimuli using response force. We sought to determine if differences in conjugate-reinforcing value of HP and LP audiovisual stimuli are observed as measured by response force and response duration. Furthermore, consistent with Rovee-Collier and Capatides (1979) and others (e.g., MacAleese et al., 2015) who have examined responding during extinction components following conjugate reinforcement schedules, we also assessed extinction-induced variability and the degree to which responding maintained when responding did not produce changes in audiovisual stimuli (extinction) using this novel conjugate-force transducer preparation. We accomplished this by first measuring how conjugate responding on the force transducer changed as dimensions of the volume of several video clips were parametrically manipulated. We then studied how conjugate responding changed when participants earned contingent access to high-preferred and low-preferred video clips, and how responding changed during extinction components. In particular, in Experiment 1, we evaluated whether different parameters of response-contingent volume change in audiovisual stimuli conjugately reinforce responses on a force transducer. In Experiment 2, we assessed the degree to which responding was maintained when conjugate changes in the volume of audiovisual stimuli (either high-preferred or low-preferred) were provided as a consequence for exerting force on a manipulandum. In Experiment 3, we evaluated the degree to which responding was maintained across multiple extinction components.

General Method

Participants and Setting

Eighteen undergraduate students were recruited from the Auburn University psychology research pool. All participants were at least 18 years old, and each individual participated in only one of the three experiments. Participants were compensated with extra credit administered via the university psychology department. Experimental sessions were conducted in a laboratory room measuring 10 m × 7 m, which contained one table, two desks, and four chairs.

Apparatus

For the measurement of force, a brushed nickel knob, 3 cm in diameter, was rigidly attached to a beam-type force transducer (Interface, Model MB-25, Scottsdale, AZ, USA). Output from the transducer was amplified (Transducer Techniques, Model LCA-RTC, Temecula, CA, USA) and digitized by a 12-bit A/D converter (National Instruments, Model USB-6009, Austin, TX, USA) connected to Windows™ personal computer. The transducer assembly was mounted to a table top by means of a clamp such that the knob extended about 4 cm over the edge of the table and about 8 cm above the top of the table. During sessions, the only functional manipulandum was the knob attached to the force transducer. Without force applied to the knob, there was no sound associated with the video that was playing. A response was measured as force applied to the manipulandum that exceeded the minimum detectable force required to register a response (e.g., Brener & Mitchell, 1989). Pressing the knob resulted in concomitant increases to the volume of the audiovisual stimuli (when applicable) in proportion to the amount of force applied to the knob. Continuously pressing the knob at the same force did not result in any changes in the volume of the audiovisual stimuli, but continuously pressing the knob while applying different amounts of force would affect concomitant changes in volume for the audiovisual stimuli.

During sessions, participants were seated comfortably in front of the transducer. Behind the transducer, a computer monitor sat on the table. The monitor was adjusted to be approximately at eye level. The signals from the transducer were used to control the audio level of preferred video material played on the monitor. All videos were played using Windows™ MediaPlayer™ embedded into custom-developed software environment. Audio level in MediaPlayer™ was controlled by the volume setting, which ranged from 0 to 100. The computer speakers were set at a constant level throughout the present study so that the maximum volume through MediaPlayer™ (100) produced a slightly louder sound than normal listening volumes, as determined by the experimenters. It should be noted that the volume settings are not scaled in absolute sound units (e.g., 100 is not 10 times the “loudness” of a setting of 10), but by fixing the output of the speakers we could achieve a range extending progressively from no sound to a moderately loud sound across the sound setting of 0 to 100, and this progression was fixed throughout the study.

The sound setting of MediaPlayer™ was adjusted linearly by the forces registered on the transducer. The software read the force from the transducer and converted the force to the nearest gram. A session conducted without human interaction on the transducer found the natural noise or error in the system fluctuated on order of ± 0.5–0.8 g, so error in our measures varied by less than a gram. Forces were scaled by a multiplier to reach the final volume; this allowed us to change how fast force-controlled sound very quickly during conditions. The multiplied force value was divided by 1000 and that value determined the sound setting until the next sampling period. For example, if the multiplier were set to 5 and the participating exerted 1000 g (1 kg) on the transducer, the sound setting would be set to 5*1000/1000 or 5; if instead the multiplier was set to 50, the same 1000 g force would produce a sound setting of 50, a much louder volume given the same force. The sound setting could not extend below 0 or above 100, so any setting above 100 was set to 100. If the multiplier was set to 0, there would be no sound regardless of forces produced by the participant, effectively programming extinction. Force values, and therefore sound settings, were updated 40 times per second while the video played. All experimental events, force recordings, and video control were accomplished by custom-developed software written in Labview™ (National Instruments, Austin, TX, USA) by the fourth author. For additional information pertaining to the development and use of this software program, contact the second author.

Participant Instructions

Prior to the session, participants were asked to place their personal items in the corner of the room and review the consent form. Participants sat at a table in front of the laptop as the experimenter read the following instructions (based on the protocol used by MacAleese et al., 2015):

> This experiment is examining how your knob pressing on a force transducer changes while viewing different video clips on a computer monitor. You should remain at this computer/force transducer and desk for the entire session. Please do not stand up or walk around while the computer program is running. For the force transducer, some of the time, the harder your press this knob [gestures to knob], the picture and/or sound you are presented with will change in various ways. Again, sometimes it might seem like the program is not working,[1] but do not worry—I will be monitoring the program to ensure that it is working properly. Before we start the program and working with the force transducer, we first need to find out what kind of video clips you would like to view. Do you have any questions before we start?”

Following the delivery of instructions, the experimenter answered any questions before beginning the preference assessment.

Preference Assessment

The experimenter gave the participants a data sheet with a list of 15 videos spanning different categories (e.g., news bloopers, commercial compilations, science, technology, politics) with a blank space next to a descriptive title of each video. All videos contained dialogue and were freely available via video hosting websites and were played for four min. Participants were asked to rank their preference for viewing each video from 1 to 15, with 1 as the most preferred video and 15 as the least preferred video.

Experiment 1: Response Force and Conjugate Schedules

In Experiment 1, we replicated Experiment 1 from MacAleese et al. (2015) by evaluating whether different parameters of response-contingent volume change in audiovisual stimuli conjugately reinforced responses on a force transducer. That is, we multiplied the participants’ response force (g) across a series of constants (5, 25, 50, or 75) to assess the degree that different force multiplier values affected participants’ response force. In addition, we implemented an extinction component (i.e., multiplier of 0) to evaluate participants’ responding when transducer pressing did not produce any auditory stimulus changes. Based on the results of MacAleese et al. (2015), we hypothesized that response-contingent changes in auditory stimuli would conjugately reinforce responding on the force transducer, and that response force would generally co-vary with force multiplier values such that participants would exert greater force during lower-multiplier components (e.g., 5) compared to higher-multiplier components (e.g., 75).

[1] When piloting these procedures prior to this project, participants would occasionally stand up or attempt to alert the experimenter that the apparatus had “malfunctioned” during extinction components.

Method

Participants Six undergraduate students participated in this experiment.

Procedures The session began by loading the participant's selected video on the computer. A five-component mixed schedule[2] was arranged such that each component had a force multiplier value (0, 5, 25, 50, or 75) associated with a video (ranked 1–5). One video was played in each component. Under each force multiplier value, the force that the participant applied to the manipulandum would be multiplied according to the specified parameter, such that as the force multiplier increased, the participant would have to generate proportionally less force to produce video sound. The force multiplier assigned to each video was randomized across participants. All videos used in Experiment 1 were considered HP. The order of the components was also randomized across participants, except for all participants the extinction component (i.e., 0) was last. Each participant was exposed to each 4-min component once. Four-min components were selected to avoid physical fatigue that could confound extended components, and because steady-state responding has been demonstrated with conjugate reinforcement preparations within 1 or 2two min following a schedule change (e.g., MacAleese et al., 2015)

Results and Discussion

Figure 1 displays the mean peak force exerted across each component for individual participants. Peak force was defined as the maximum force applied by the participant during a response. Mean peak force was calculated by dividing the mean peak force of each response within a component by the number of responses within each component. For five of six participants, mean peak force tended to decrease as force multipliers increased. This result is most clearly demonstrated in P-01, P-04, and P-06. Indeed, five of the six participants exerted the greatest average peak force on the 5-multiplier component, and three of the participants exerted the least amount of force during the 75-muliplier component. It is interesting that, with the exception of P-04, mean peak force was variable, but overall high, during extinction components. On average, participants exerted less peak force by response during the 75-multiplier component ($M = 131.57$) than the 50-multiplier component ($M = 1043.89$), the 25-multiplier component ($M = 1265.17$), the 5-multiplier component ($M = 1672.75$), and during the extinction (i.e., 0) component ($M = 1719.52$). Thus, results from Experiment 1 suggest an inverse relation between peak response force and force multiplier components, such that participants' response force tended to decrease and force multipliers increased. However, mean peak force was relatively high across participants during extinction components even when there was no functional response–reinforcer relation between the amount of force applied to the manipulandum and change in audio stimuli. This pattern was likely due to increased responding at the onset of extinction characteristic of extinction-induced responding. Given that the 5-multiplier component required proportionally more response effort than the other (25, 50, and 75) parameters and participants tended to exert the most force during the 5-multiplier components, we sought to determine if differences in mean peak force were observed across HP and LP audiovisual stimuli using the 5-multiplier parameter in Experiment 2.

[2] We use the term "mixed schedule" although these are not pure mixed schedules because unique stimuli were presented for each schedule component. Each new video served to signal a change in the component but did *not* signal the reinforcement schedule.

Experiment 2: Evaluating Differences between HP and LP Stimuli

Results from Experiment 1 indicate an inverse relation between peak force and force multiplier components, such that peak force covaried with changes to the amount of force required to produce conjugate changes in audiovisual stimulation. In general, participants tended to exert the most force during the 5-multiplier component. In Experiment 2, we evaluated the degree to which responding was maintained when conjugate changes in the volume of audiovisual stimuli (either HP or LP) were provided as a consequence for exerting force during a series of 5-multiplier components on the manipulandum. In addition, this experiment assessed the degree to which the duration of responding differed according to the conjugate changes of the audiovisual stimuli.

Method

Participants Seven undergraduate students participated in this experiment.

Procedures A two-component mixed schedule was arranged such that each HP and LP video was associated with a force multiplier of 5. The HP components used videos ranked 1–4, and the LP components used videos ranked 12–15. Like Experiment 1, each new video served to signal a change in the component but did not signal the reinforcement schedule. The sequence of HP and LP components was randomized across participants, with the exception that the same component could not be presented more than twice in a row. Participants were exposed to the HP and LP components four times each. All components were 4 min. Due to a software malfunction, only data from the first four components for P-14 were recorded.

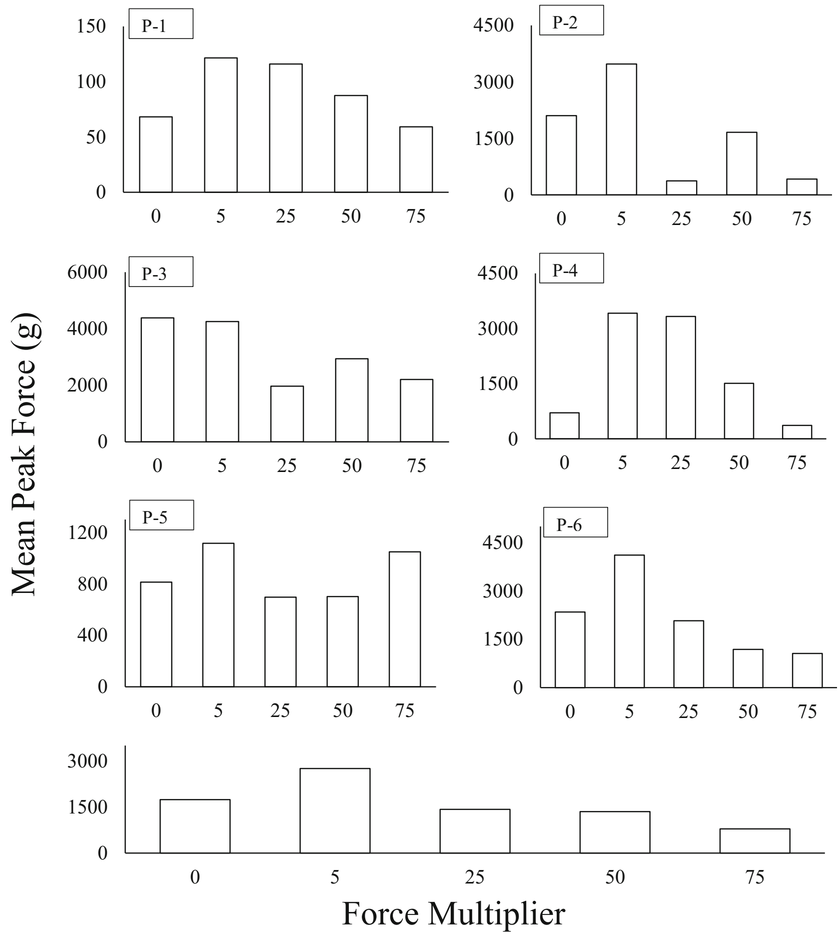

Fig. 1 Mean peak force by force multiplier component for P-1 (top panel, left), P-2 (top panel, right), P-3 (second panel, left), P-4 (second panel, right), P-5 (third panel, left), P-6 (third panel, right), and averaged across all participants (bottom panel)

Results and Discussion

Table 1 displays the mean peak force, mean response duration in second(s), and number of responses for each participant across components. Figure 2 displays the mean peak force exerted across each component for individual participants. Four of the seven participants (P-12, P-13, P-14, and P-17) exerted higher average peak force during HP components than LP components, whereas three participants (P-15, P-16, and P-18) exerted higher peak force on LP components relative to

Table 1 Response peak force, duration, and frequency by component in experiment 2

Participant	Component	Mean peak force (g)	Mean response duration (s)	Response freq.
12	HP	978 (475)	160 (110)	8
	LP	719 (375)	91 (116)	8
13	HP	1622 (2843)	80 (58)	30
	LP	534 (844)	7 (13)	113
14	HP	1968 (1854)	69 (47)	8
	LP	518 (457)	9 (10)	70
15	HP	723 (476)	171 (125)	7
	LP	898 (40)	243 (1)	4
16	HP	1246 (764)	96 (104)	11
	LP	1792 (1011)	138 (123)	8
17	HP	1107 (766)	200 (124)	6
	LP	1064 (1281)	180 (124)	6
18	HP	1210 (607)	62 (65)	39
	LP	1942 (65)	85 (90)	13

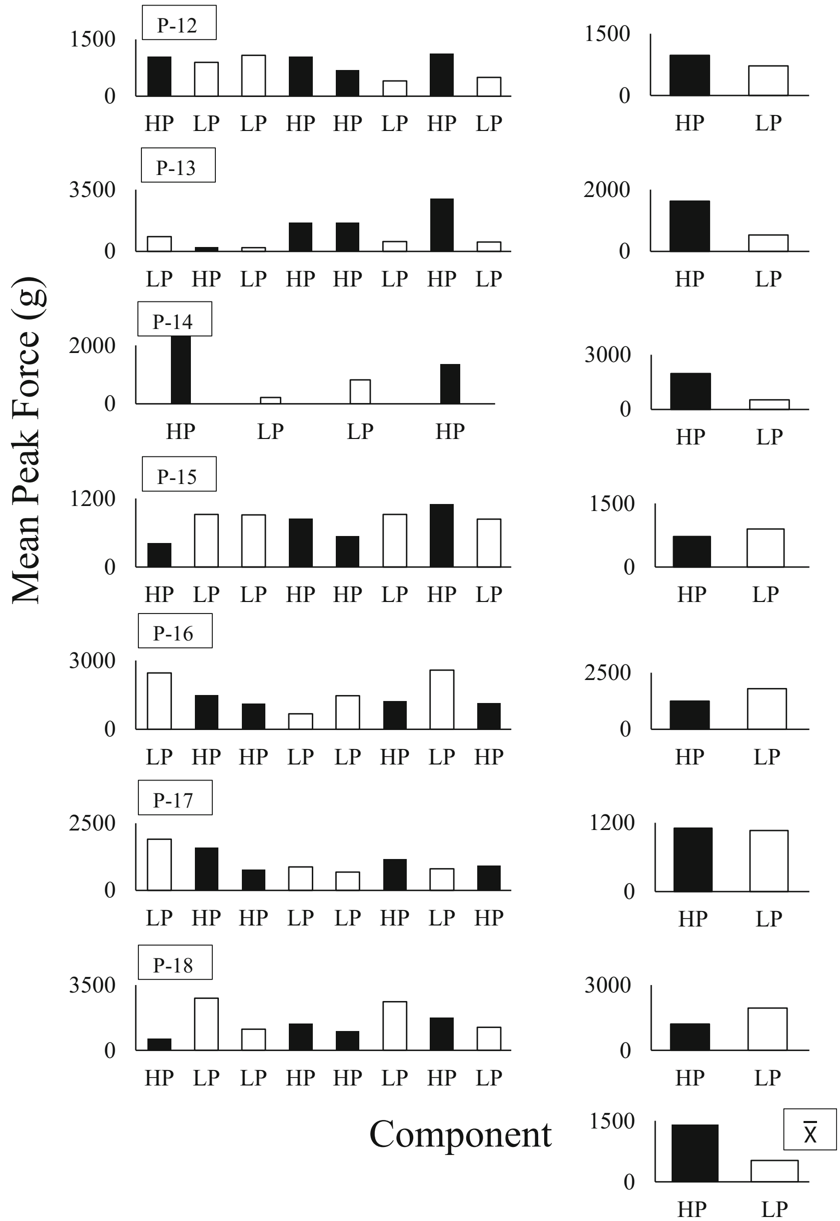

Fig. 2 Mean peak force by component (left) and averaged across components (right) for P-12, (top panel), P-13 (second panel), P-14 (third panel), P-15 (fourth panel), P-16 (fifth panel), P-17 (sixth panel), P-18 (seventh panel), and averaged across participants (bottom panel)

HP components. On average, participants exerted more peak force by response during HP components ($M = 1401.00$) than LP components ($M = 524.12$) and response durations were generally longer during HP components ($M = 52.46$) compared to LP components ($M = 19.27$). Thus, on the whole participants exerted greater peak force during HP components than LP components, and conjugate changes in HP stimuli maintained participant responding for a greater duration of time than conjugate changes in LP stimuli, suggesting that HP audiovisual stimuli are more conjugately reinforcing than LP stimuli. However, mean peak force was greater during LP components compared to HP components for three of seven participants, and the difference in mean peak force between HP and LP stimuli was particularly small for one participant (P-17), suggesting the extent to which relative preference for audiovisual stimuli maintain conjugate responding may be limited and idiosyncratic across individuals. Thus, caution should be exercised when interpreting these results, because additional research is needed to further evaluate the extent to which relative preference in audiovisual stimuli differentially maintain responding within conjugate response-force measurement contexts.

Experiment 3: Assessing Conjugate Responding during Extinction

In Experiment 2, participants exerted greater peak force during HP components than LP components, and conjugate changes in HP stimuli maintained participant responding for a greater duration of time than conjugate changes in LP stimuli, suggesting that HP stimuli are more conjugately reinforcing than LP stimuli in this conjugate preparation. Consistent with MacAleese et al. (2015), who examined responding during extinction components within conjugate reinforcement contexts, in this experiment we evaluated the degree to which responding maintained when responding did not produce changes in audiovisual stimuli. That is, we assessed the degree to which responding was maintained (a) when conjugate changes in the volume of audiovisual stimuli were provided as a consequence for exerting force on the manipulandum and (b) across multiple extinction components. We hypothesized that participants' responses would be characteristic of extinction-induced responding (e.g., increased response rate, strength; Podlesnik, Kelley, Jiminez-Gomez, & Bouton, 2017) in extinction components following reinforcement components.

Method

Participants Five undergraduate students participated in this experiment.

Procedures HP stimuli were used as reinforcers to promote responding across components. A two-component mixed schedule was arranged such that each HP component was associated with a force multiplier of 5 and the extinction components were associated with a force multiplier of 0. The HP components used videos ranked 1–4, the extinction components used videos ranked 7–10. Results from Experiment 2 suggest that low or moderately preferred videos will support responding, though to a lesser degree than HP videos. Thus, any increase in force observed during extinction components is attributable to the change in schedule (e.g., extinction) as opposed to the relative value of the visual stimulation. Likewise, any changes in response rate during the extinction components are also attributable to the change in schedule (e.g., MacAleese et al., 2015; Rovee-Collier & Capatides, 1979). The sequence of components was ordered such that the first four components consisted of HP components followed by four extinction components. All components were 4 min. Participants' response rates and maximum peak force applied to the transducer for each extinction component were compared to the last HP component. Due to a software malfunction, only three HP components for P-20 were recorded.

Results and Discussion

Table 2 displays the mean peak force, mean response duration, and number of responses for each participant across components. Figure 3 depicts peak force by response for P-19, P-20, P-21, P-22, and P-23. All five participants demonstrated considerable variability in their peak force across responses during extinction components. On average, participants exerted higher peak force during HP components ($M = 2204.50$) than extinction components ($M = 1754.69$), and the duration of participants' responding was greater during the HP components ($M = 53.94$) than during extinction components ($M = 6.14$). Notably, participants' response patterns were characteristic of extinction-induced responding during extinction components (Table 3). That is, all five participants exerted a higher maximum peak force on a single response in the first extinction component (EXT-1) than during a single response in the last HP component. Likewise, for the second (EXT-2) and third (EXT-3) extinction components as well, participants' maximum peak force on a single response was greater than during the previous HP component. For the fourth extinction component (EXT-4), four (P-20, P-21, P-22, P-23) of the five participants exerted greater maximum peak force on a single response during extinction than during the previous HP component. In total, maximum peak force for a single response increased in 19 of the 20 extinction components conducted across all five participants compared to their previous maximum peak force on a single response during the last HP component. Likewise, participants' response rates also increased during each extinction component relative to response rates

Table 2 Response peak force, duration, and frequency by component in experiment 3

Participant	Component	Mean peak force (g)	Mean response duration (s)	Response freq.
19	HP	2296 (905)	46 (50)	13
	EXT	1498 (1901)	7 (12)	97
20	HP	1672 (861)	53 (39)	27
	EXT	2574 (2311)	2 (4)	101
21	HP	2749 (1926)	98 (113)	10
	EXT	2238 (1760)	22 (40)	45
22	HP	2402 (1328)	121 (121)	9
	EXT	3905 (2286)	57 (57)	27
23	HP	2544 (1456)	167 (125)	8
	EXT	2367 (2391)	2 (2)	191

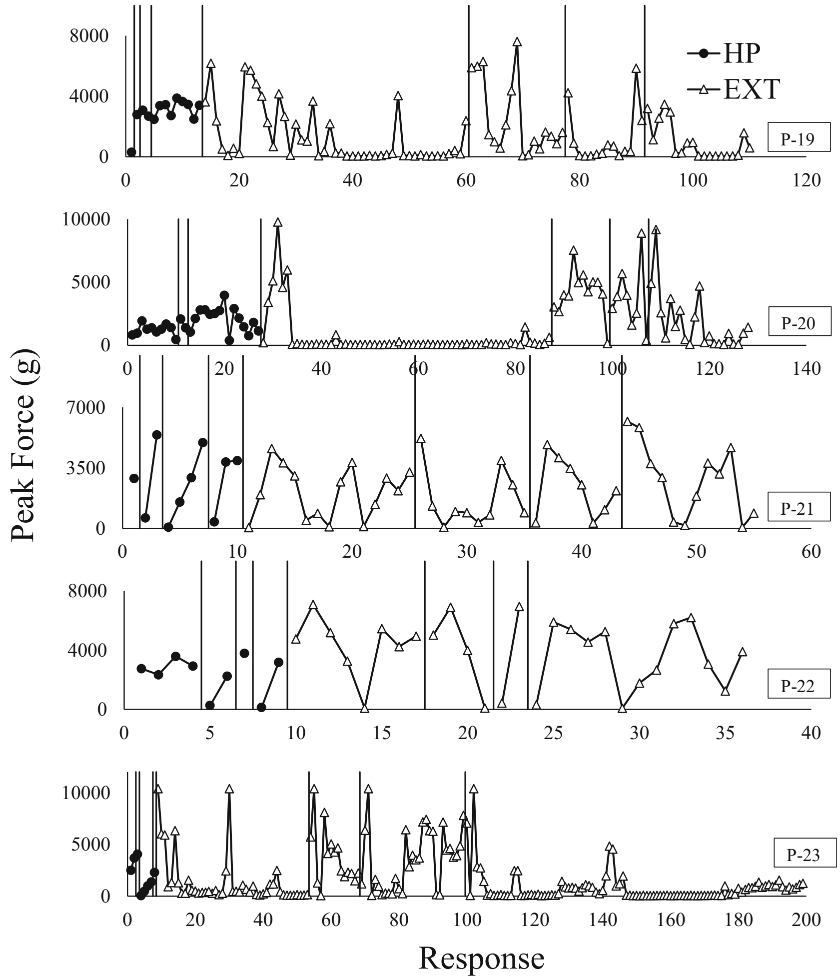

Fig. 3 Peak force by response for P-19, (top panel), P-20 (second panel), P-21 (third panel), P-22 (fourth panel), and P-23 (bottom panel)

during the last HP component, increasing in 16 of the 20 extinction components conducted across all five participants. Thus, HP stimuli conjugately reinforced responding on the transducer across multiple reinforcing components, and all participants displayed responding characteristic of extinction-induced variability (i.e., increased maximum peak force) during the initial extinction component that followed reinforcing components.

General Discussion

Overall, results from this study suggest response force reveals interesting patterns of reinforcer efficacy in a conjugate schedule framework. Results from Experiment 1 indicate an inverse relation between peak force and force multiplier components, such that peak force covaried with changes to the amount of force required to produce conjugate changes in audiovisual stimulation. In Experiment 2, on average participants exerted greater peak force during HP components than LP components, and conjugate changes in HP stimuli generally maintained participant responding for a greater duration of time than conjugate changes in LP stimuli. It is notable, however, that mean peak force was greater during LP components compared to HP components for three of seven participants, and the difference in mean peak force between HP and LP stimuli was indistinguishable for one participant. In sum, four of seven participants exerted greater mean peak force during HP components compared to LP components, though the extent to which conjugate responding is differentially maintained across HP and LP stimuli is still unclear and idiosyncratic across individuals. Nonetheless, these results extend the result of MacAleese et al. (2015), who did not assess the extent to which LP stimuli conjugately reinforced target behavior at all. Extant literature suggests a relation between relative preference and reinforcer effectiveness (e.g., Lee et al., 2010; Piazza et al., 1996). Given that LP stimuli may maintain behavior under single-schedule arrangements (Glover et al., 2008), the conjugate responding by participants in Experiment 2 in LP components is not necessarily surprising. However, HP stimuli generally function as more effective reinforcers under increased response requirements (e.g., Glover et al., 2008; Roane, 2008), consistent with our results from four of seven participants in Experiment 2.

Table 3 Maximum peak force and response rate by component in experiment 3

Participant	Component	Max force (g)	Resp/Min	Increase in Max force?	Increase in Resp rate?
19	HP	3879	2.25	–	–
	EXT-1	6182	11.75	Yes	Yes
	EXT-2	7621	17.00	Yes	Yes
	EXT-3	5861	14.00	Yes	Yes
	EXT-4	3473	4.75	No	Yes
20	HP	3957	3.75	–	–
	EXT-1	9756	15.00	Yes	Yes
	EXT-2	7540	3.00	Yes	No
	EXT-3	8890	2.00	Yes	No
	EXT-4	9176	5.25	Yes	No
21	HP	3920	0.75	–	–
	EXT-1	4626	3.75	Yes	Yes
	EXT-2	5204	2.50	Yes	Yes
	EXT-3	4854	2.00	Yes	Yes
	EXT-4	6186	3.00	Yes	Yes
22	HP	3187	0.50	–	–
	EXT-1	7086	2.00	Yes	Yes
	EXT-2	6907	1.00	Yes	Yes
	EXT-3	6959	0.50	Yes	No
	EXT-4	6209	3.25	Yes	Yes
23	HP	2291	0.25	–	–
	EXT-1	10388	11.25	Yes	Yes
	EXT-2	10387	3.75	Yes	Yes
	EXT-3	10387	7.75	Yes	Yes
	EXT-4	10387	25.00	Yes	Yes

In Experiment 3, participants exerted significantly higher mean peak force during HP components than extinction components and the duration of participants' responding was much greater during the HP components than during extinction components. Participants demonstrated considerable variability in their maximum peak force during multiple extinction components, though all participants exhibited increased maximum peak force during initial extinction components relative to the previous HP component. Thus, the current conjugate preparation may be useful for researchers evaluating extinction under continuous schedules of reinforcement, particularly relating to force dynamics (i.e., maximum peak response force) and extinction-induced variability. Participants exerted more peak force during HP components in Experiment 3 than Experiment 2, possibly suggesting that interspersing LP stimuli with HP stimuli may serve to decrease the amount of force, which in turn decreases obtained conjugate reinforcement across reinforcing components.

Although FR schedules are often used to measure response effort, force dynamics may prove to be a useful adjunctive index of effort to be used in the study of stimulus preference and reinforcer effectiveness. For example, response force could be manipulated within a progressive ratio arrangement to produce a progressive force schedule of reinforcement, in which the threshold for response force is systematically increased to identify stimuli that maintain responding under increased response requirements. Given that audiovisual stimuli (e.g., access to iPads, augmentative communication devices) are commonly used within many clinical assessment and treatment contexts (e.g., Cook, Rapp, Burji, McHugh, & Nuta, 2017; Falligant & Pence, 2017), effectively identifying audiovisual stimuli that are reinforcing and engaging is crucial to clinical outcomes. Thus, future applied research might extend results from the current project by incorporating force dynamics within extant stimulus preference assessments for audiovisual stimuli.

Response force within conjugate reinforcement contexts may also have utility in the assessment of extinction-related phenomena and resistance to change, because results from the current project demonstrate unique patterns of responding during extinction components that may be observed in conjugate reinforcement contexts with response force. Furthermore, force dynamic in conjugate schedules may hold clinical utility in the assessment and treatment of automatically reinforced behavior such as stereotypy (Rapp, 2008), because results from the current project suggest the interspersal of LP stimuli in sequences of HP stimuli may be associated with decreased response force. That is, future research should evaluate how response-contingent access to LP stimuli influences the amplitude of subsequent stereotypic behavior that contacts preferred stereotypic events or stimulation. Future research should also parametrically compare the reinforcing efficacy of HP and LP stimuli under different response requirements or force multipliers (e.g., 5-multiplier vs. 75-multiplier) to evaluate the degree to which differences in reinforcer effectiveness are moderated by parameters of the response requirements.

Additional research should replicate results from the current study using stimuli identified by commonly used stimulus preference assessment procedures (e.g., multiple-stimulus without replacement; DeLeon & Iwata, 1996), given that the preference assessment used in the current study relied on participants' self-reports using a survey-style preference measure. In addition, future research should further evaluate, among hierarchies of high-preferred and low-preferred stimuli, the impact of relative preference on conjugate responding. In the current project, a range of high-preferred and low-preferred stimuli were used, though it is possible that only using the single highest and single lowest preferred stimuli may have affected the degree to which responding was (not) maintained. In future investigations of conjugate responding and audiovisual stimuli using similar experimental preparations, researchers should use a standard measure of volume (e.g., decibels) to ensure consistent volume across components. A potential limitation of this project, although the speaker volume of the laptop was held constant across components and participants in the current project, we did not record a standard measure of video volume. In addition, in Experiment 3 HP videos were used in the reinforcing components whereas moderately preferred videos were used during extinction components. Thus, observed differences in mean peak force and response duration across all responses and components may be attributable to differences in relative preference for stimuli used in the different components. Nevertheless, the response patterns characteristic of extinction-induced responding (e.g., at least one response with a higher maximum force during extinction compared to the last HP component) were still observed with moderately preferred stimuli, highlighting the robustness of our findings concerning extinction-induced responding.

Future research should compare responding under HP and extinction components while holding the relative preference of the videos across the HP/extinction components equal, because videos used in the extinction components were considered moderately preferred (with the exception of Experiment 1). Although research suggests moderately preferred stimuli (or low preferred stimuli, as demonstrated in Experiment 2) still effectively function as reinforcers (e.g., Piazza et al., 1996), it would be important to further evaluate differences in mean peak force between HP and extinction components with highly preferred stimuli used in all components. Given the need for behavior analysts to develop novel laboratory approaches and technologies for evaluating behavior of interest (Mace & Critchfield, 2010), the conjugate preparation developed in the current study may serve to advance the nomological network of translational behavioral science. As described by Vollmer (2011), translational behavioral research may yield significant clinical applications while also advancing our understanding of basic behavioral processes, so continued research in this area is much needed.

Compliance with Ethical Standards

Conflict of Interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent Informed consent was obtained from all individual participants included in the study.

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